Woods Hole Oceanographic Institution

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Technical Report

September 1996

Arabian Sea Mixed Layer Dynamics Experiment

Mooring Recovery Cruise Report

R/V *Thomas Thompson* Cruise Number 52

14 October- 25 October 1995

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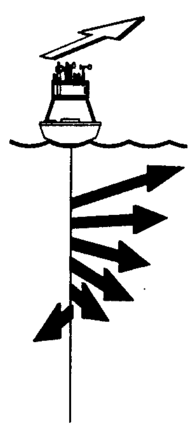

Upper Ocean Processes Group

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Woods Hole, Massachusetts 02543 U.S.A.

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Approved for Distribution:

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Abstract

An array of surface and subsurface moorings was deployed in the Arabian Sea to provide high quality time series of local forcing and upper ocean currents, temperature, and conductivity in order to investigate the dynamics of the ocean's response to the monsoonal forcing characteristic of the area. The moored array was first deployed during R/V *Thomas Thompson* cruise number 40; recovered and redeployed during R/V *Thomas Thompson* cruise number 46 and recovered to conclude the deployment during R/V *Thomas Thompson* cruise number 52.The array was part of the Office of Naval Research (ONR) funded Arabian Sea experiment.

This report describes, in a general manner, the work that took place during the R/V *Thomas Thompson* cruise number 52. A detailed description of the Woods Hole Oceanographic Institution (WHOI) surface mooring and its instrumentation is provided. Information about the XBT and CTD data and near surface temperature data collected during the cruise is also included.

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Section 1: Introduction

The R/V *Thomas Thompson* cruise number 52 (TN052) departed Muscat, Oman, on 13 October 1995 at 1000 UTC. The purpose of the cruise was to recover one Woods Hole Oceanographic Institution (WHOI) surface mooring, two Scripps Institution of Oceanography (SIO) surface moorings and two University of Washington (UW) subsurface profiling current meter (PCM) moorings. All of the moorings were part of the Office of Naval Research (ONR) funded Arabian Sea experiment. This was the third of three cruises planned for the experiment. See Trask *et al.* (1995a, 1995b) for the previous cruise reports. The mooring deployment schedule for the three cruises is shown in Figure 1.

The cruise involved personnel from WHOI, SIO, University of Southern California (USC), Lamont Doherty Earth Observatory (LDEO), and UW. Appendix 1 lists the cruise participants. Figure 2 shows the cruise track and the mooring locations.

Expendable bathythermograph (XBT) data and CTD data were collected while in transit to the site and at mooring locations. The XBT data was collected hourly while en route. The XBT positions appear in Appendix 2. 151 T-7 XBT's were deployed. A total of five CTD casts were made throughout the cruise. These profiles were done in conjunction with each mooring site. Appendix 3 contains a listing of the CTD positions, start times and maximum depth of the stations. Real time weather data was recorded during the cruise using the ship's meteorological system and WHOI designed portable meteorological system. Details of the portable meteorological system can be found in section 2B and in greater detail in Payne (1995).

Tables 1 and 2 list the moored array deployment and recovery dates for the first and second settings respectively as well as the surveyed anchor positions.

In addition to this introduction, this report has two sections. The first section primarily describes the mooring recovery procedures that were used; the second section details the initial observations of the instrumentation that were recovered from the WHOI mooring.

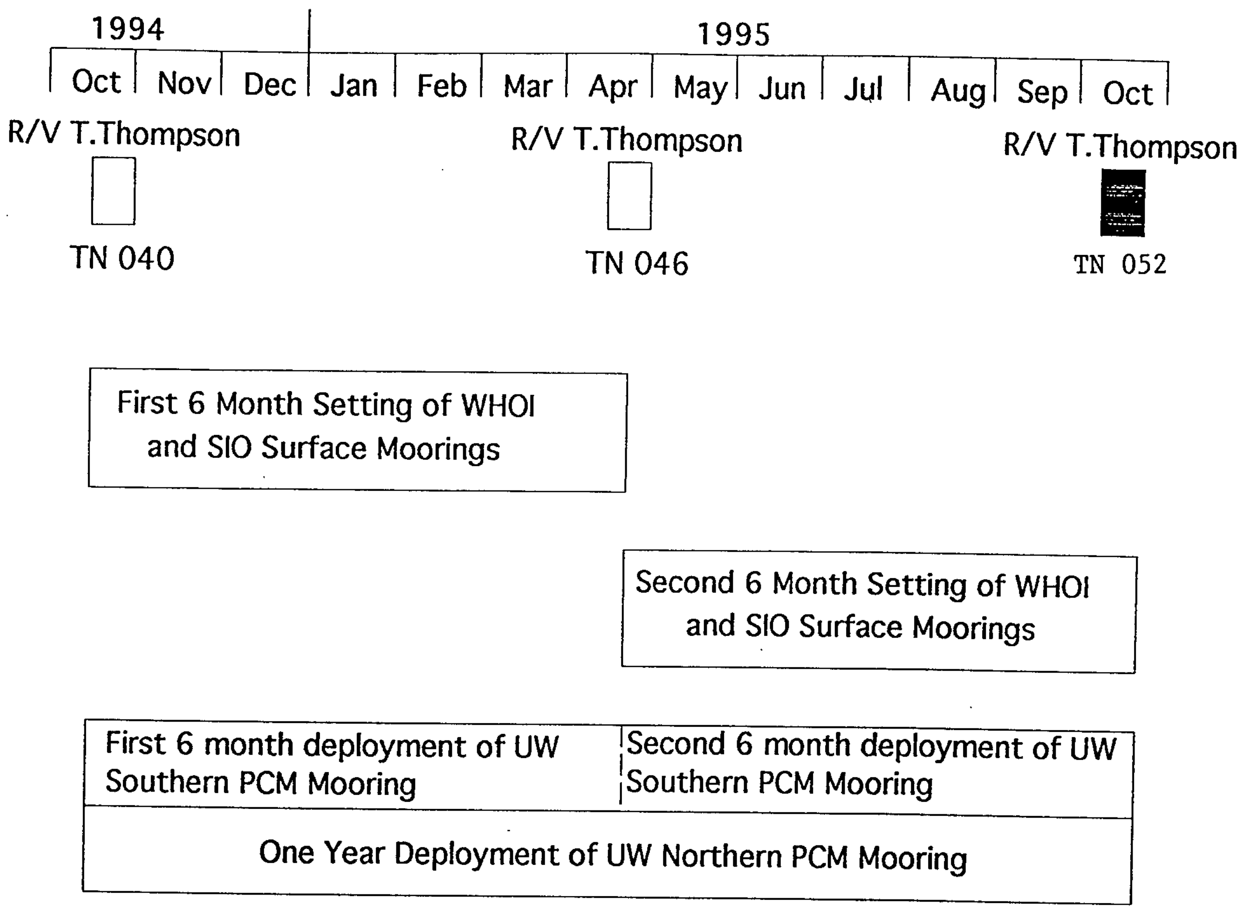

Figure 1: Arabian Sea mooring cruise schedule.

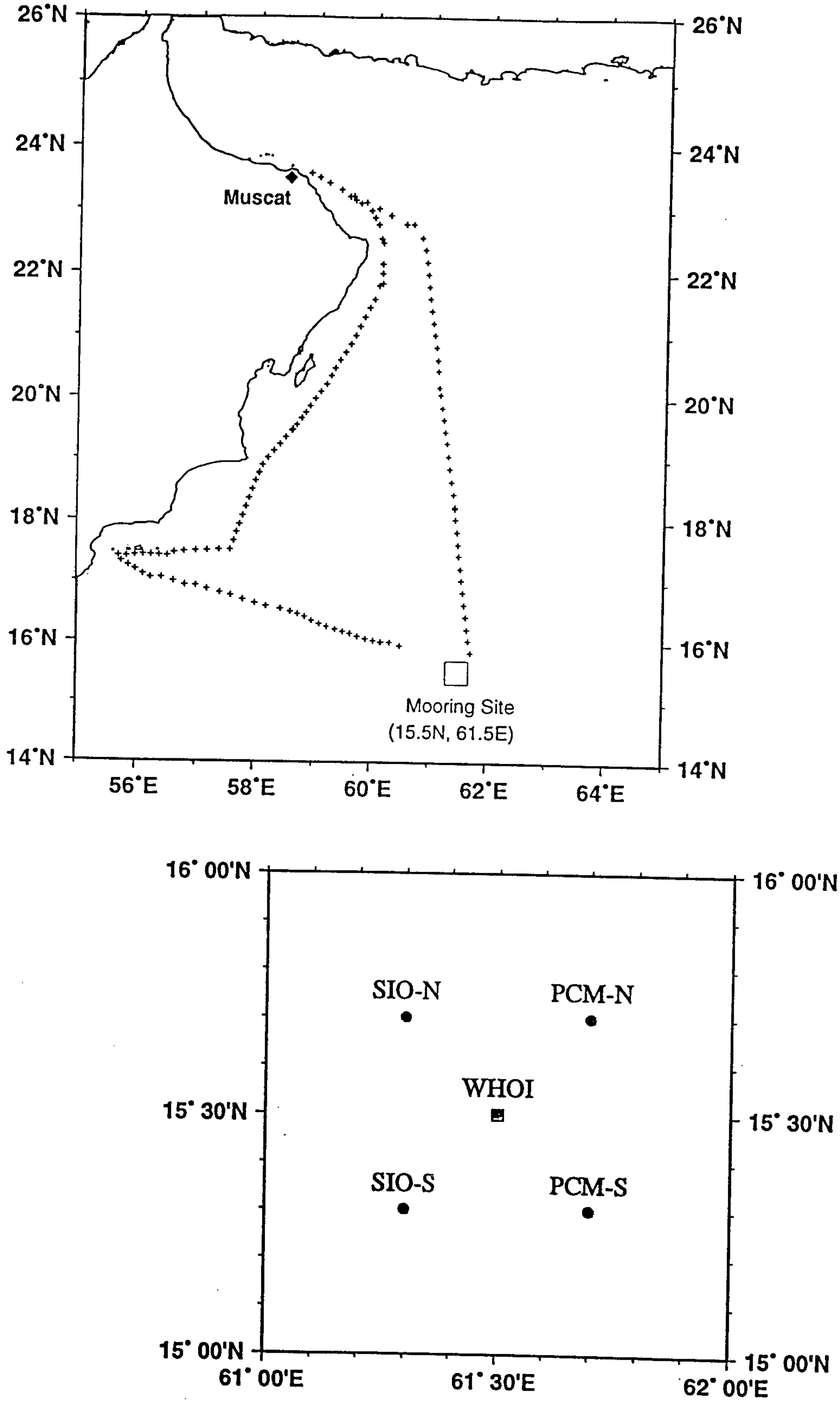

Figure 2: Cruise track, XBT and mooring locations.

Table 1. Arabian Sea 1 Mooring Deployment Information

Mooring	Deployment Date and Time	Recovery Date	Anchor Position
WHOI Discus Buoy (WHOI Moor. Reference No. 975)	15 October 1994 @1048 UTC	20 April 95 @0105 UTC	15°30.04'N 61°29.99'E
SIO Northern Buoy	17 October 1994 @0723 UTC	16 April 95 @ 1055 UTC	15°43.53'N 61°15.94'E
SIO Southern Buoy	18 October 1994 @0649 UTC	23 April 95 @ 0652 UTC	15°16.53'N 61°16.11'E
UW Northern PCM	23 October 1994	16 October 95 @ 0210 UTC - Bottom section	15°43.90'N 61°44.53'E
UW Southern PCM (WHOI Moor. Reference No. 970)	19 October 1994	18 April 95 @ 0150 UTC - Top section @ 0425 UTC - Bottom section	15°16.37'N 61°44.07'E

Table 2. Arabian Sea 2 Mooring Deployment Information

Mooring	Deployment Date and Time	Recovery Date	Anchor Position
WHOI Discus Buoy (WHOI Moor. Reference No. 975)	22 April 1995 @ 0939 UTC	10 October 1995 @1000 UTC	15°30.07'N 61°30.05'E
SIO Northern Buoy	17 April 1995 @ 0715 UTC	19 October 95 @0601 UTC	15°43.39'N 61°15.86'E
SIO Southern Buoy	24 April 1995 @ 0716 UTC	18 October 95 @ 0712 UTC	15°16.52'N 61°16.12'E
UW Northern PCM (WHOI Moor. Reference No. 972) recovered / deployed	23 October 1994	17 July 1995 upper section 16 October 1995 @ 0210 UTC - Bottom section	15°43.90'N 61°44.53'E
UW Southern PCM (WHOI Moor. Reference No. 976)	25 April 1995 @ 0650 UTC	17 October 1995 @ 1000 UTC	15°16.11'N 61°43.82'E

* The Northern PCM failed in July 1995 and the upper section of the mooring was recovered during R/V *Thomas Thompson* cruise TG 049.

Section 2: The Moored Array

Five moorings were recovered during cruise number 52 of the R/V *Thomas Thompson*. The central mooring in the array was a WHOI/UOP group surface mooring with meteorological and oceanographic instrumentation. The WHOI mooring will be described in greater detail in the following section.

To the west of the WHOI mooring were two SIO surface moorings utilizing 7'-6" diameter toroid-shaped buoys for their primary flotation. The SIO moorings were given a north and south designation. The SIO buoys were outfitted with a tower that contained two redundant meteorological systems measuring wind speed and direction, air temperature, sea surface temperature, short-wave radiation, and barometric pressure. The subsurface instrumentation on each SIO mooring included a downward-looking ADCP mounted in the buoy bridle and ten temperature recorders mounted on the wire in the upper 190 meters. Two additional temperature recorders were added to the second setting of the southern SIO surface mooring at 170 and 190 meters.

To the east of the WHOI surface mooring there were two UW subsurface profiling current meter (PCM) moorings. These were given a north and south designation. The PCM was designed to cycle between 26 and 202.5 meters. The PCM mooring was a two-part mooring. The upper section contained a steel sphere, the profiling current meter, guide line and acoustic release. The lower section was a standard subsurface mooring with a 2000 pound buoyancy syntactic foam sphere as the primary buoyancy and distributed glass ball buoyancy along the mooring and at the bottom. These two sections were separated by an acoustic release. The upper part of the mooring was recovered first by firing the upper release so as to minimize the chances of damaging the profiling current meter. Both PCM moorings had a WHOI temperature logger mounted on the top sphere of the mooring at approximately 20 meters depth and another at approximately 250 meters depth. The southern PCM mooring had five WHOI Vector Measuring Current Meters (VMCM) at depths of approximately 300, 500, 750, 1500 and 3000 meters.

Figure 3 schematically shows all five moorings and the location of the subsurface instrumentation.

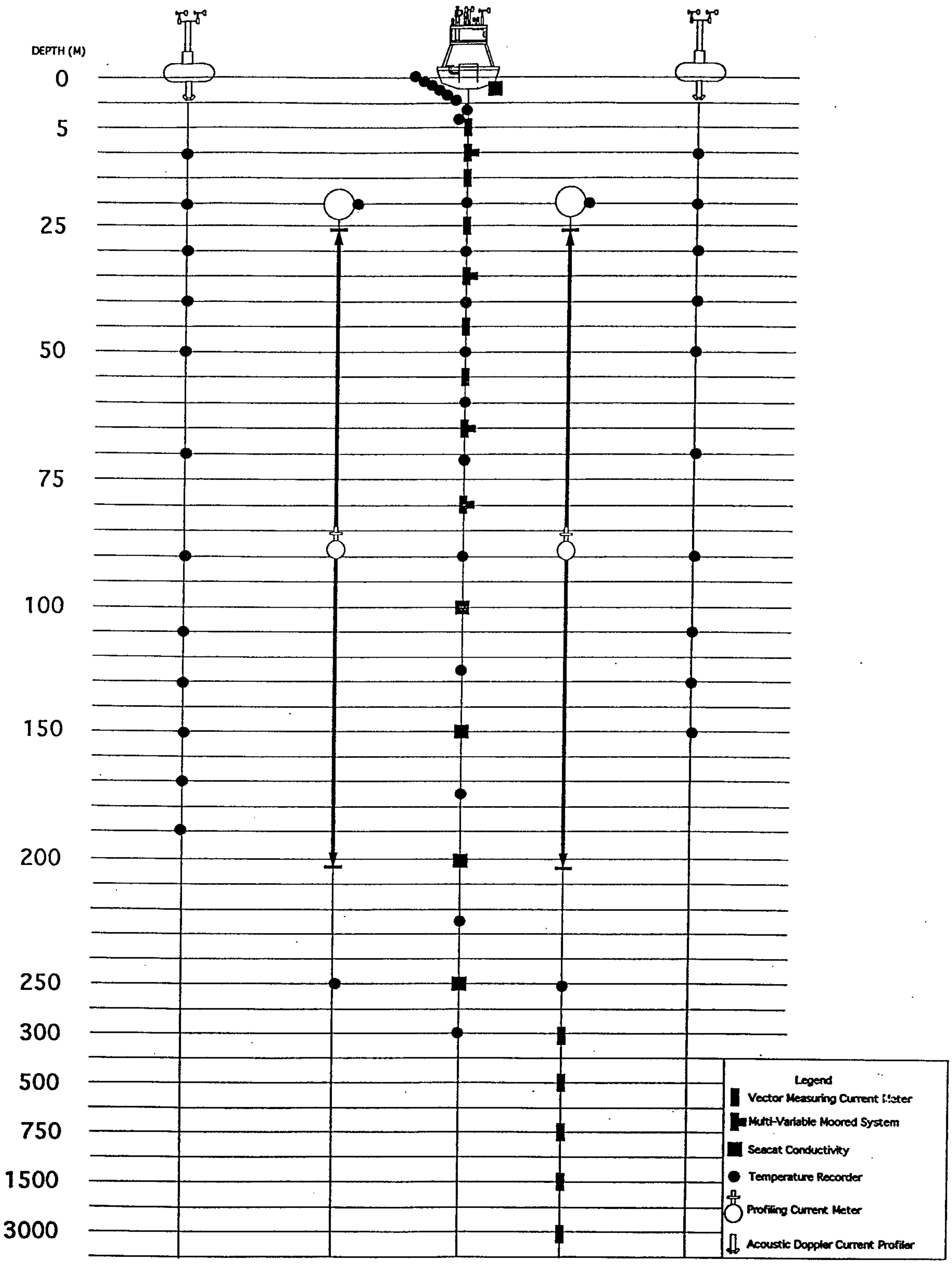

Figure 3: Arabian Sea moored array instrument locations.

Both the northern and southern PCM moorings were intended to be deployed for one year. However during the October 1994 deployment it was determined that the desired depth of the top sphere was considerably less than the design depth of 20 meters. The northern PCM mooring was so shallow that the top occasionally came to the surface after it was deployed. The problem was traced to incorrect depth recorder readings which affected both PCM moorings deployed during the October cruise. The northern mooring was recovered and redeployed during the deployment cruise in October 1994 using the spare anchor that was onboard at the time. The southern PCM was left in until the April 95 turnaround cruise at which time the mooring was recovered and redeployed.

The northern PCM guide line that was used for the first setting was replaced due to damage during the recovery. A special field replaceable guide line, that had one end of the wire terminated with a removable two piece end fitting was used. Normally when prepared ashore, the end termination attached to the guide line wire is a single piece, closed swage socket. During July 95 the guide line of the northern PCM mooring failed causing the PCM to slide off the guide line and be lost. The failure point was at the two-piece swage termination. The upper sphere and attached guide line were recovered during R/V *Thompson* cruise TN049 on 17 July 95. Upon initial inspection of the recovered end fitting, it was concluded that the failure was caused by cyclic fatigue around the threads of the end fitting. Additional analysis of the failure is planned.

A. WHOI Surface Mooring

The WHOI mooring deployed in the Arabian Sea is shown schematically in Figure 4. The mooring is an inverse catenary design utilizing wire rope, chain, nylon and polypropylene line and has a scope of 1.22 (Scope = slack length/water depth).

The surface buoy is a three-meter diameter discus buoy with a two-part aluminum tower and rigid bridle. Eighteen meteorological sensors are mounted on the top half of the buoy tower and are described in the following section. Ten near-surface oceanographic sensors are attached to the bridle and buoy hull. In addition to the buoy-mounted instruments, the mooring supports an additional 27 recording packages, some of which have multiple sensors. The subsurface instrumentation recovered during this cruise is shown in Table 3.

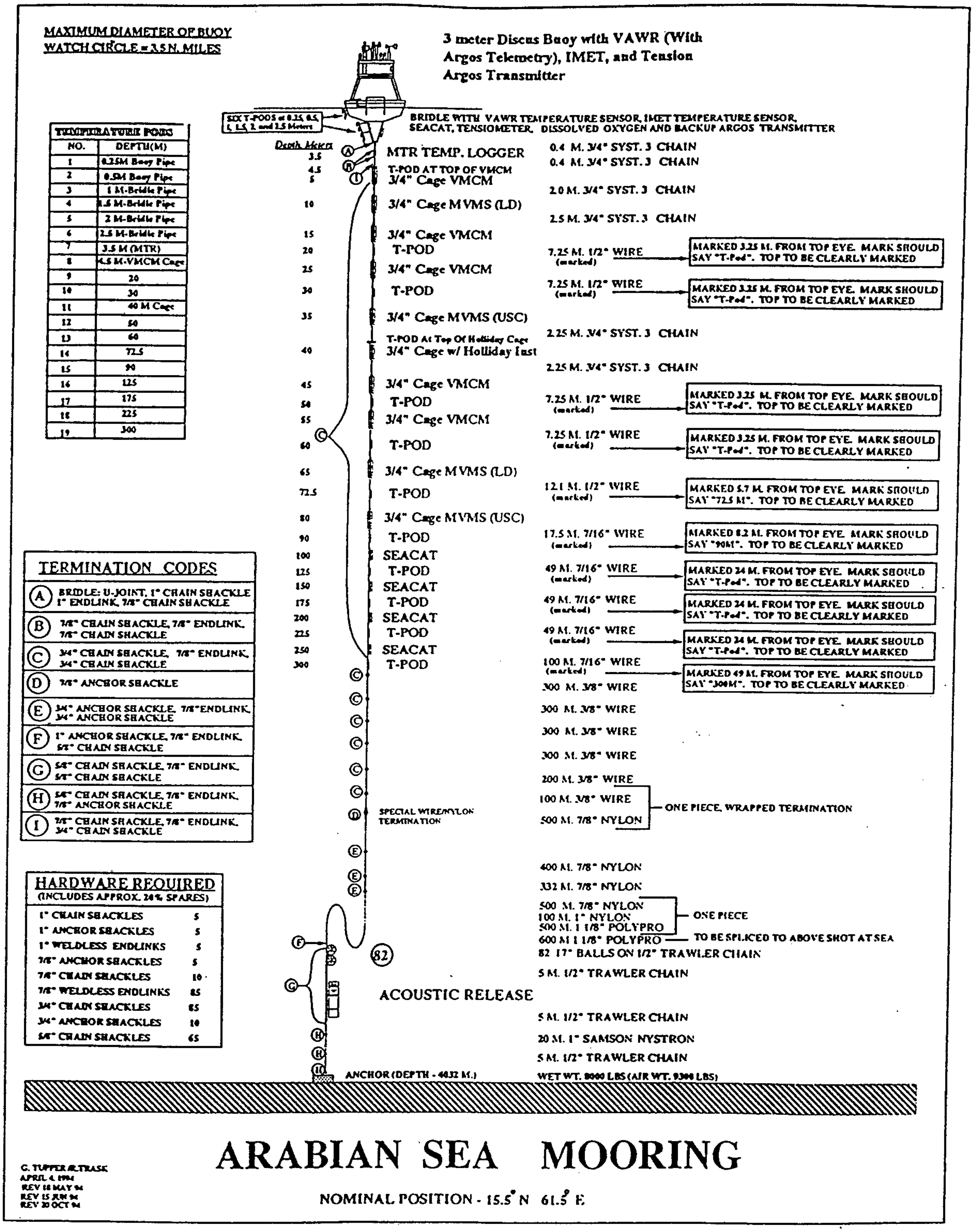

Figure 4: WHOI surface mooring schematic.

Table 3: Arabian Sea Moored Array Instrumentation

April to October 95

Depth (m)	SIO-S	UW-S PCM	WHOI	UW-N PCM	SIO-N
0.25			T-3291		
0.5			T-3299		
1			T-3280		
1			SST V720WR		
1			IMET SST		
1.5	ADCP 195		T-3263		ADCP 196
1.5			SEACAT 928		
1.5			DO S/N 60		
2			T-3274		
2.5			T-3271		
3.5			MTR-3250		
4.5			T-3341		
5			VM-050		
10	SIO T-5467		LD MVMS 203805		SIO T-3267
15			VM-030		
20	SIO T-5459	T-3835	T-4488	T-3279	SIO T-3311
25			VM-034		
30	SIO T-5464		T-3283		SIO T-5461
35			USC MVMS 200203		
40	SIO T-5466		BIO-ACOUSTIC		SIO T-5456
40			T-3309		
45			VM-003		
50	SIO T-5455		T-4492		SIO T-5465
55			VM-014		
60			T-3296		
65			LD MVMS 500301		
70	SIO T-5457	PCM 08-1		PCM 07-2	SIO T-3710
72.5			T-3699		
80			USC MVMS 200201		
90	SIO T-3714		T-2535		SIO T-5458
100			SEACAT 927		
110	SIO T-3282				SIO T-3302
125			T-2536		
130	SIO T-3304				SIO T-5462
150	SIO T-3316		SEACAT 144		SIO T-5463
170	SIO T-3285				
175			T-3308		
190	SIO T-5460				
200			SEACAT 929		
225			T-3702		
250		T-2533	SEACAT 142	T-2541	
300		VM-016	T-4495		
500		VM-018			
750		VM-021			
1500		VM-025			
3000		VM-038			

Legend

T-####	WHOI Temperature Recorder
SIO T-####	SIO Temperature Recorder
Seacat ###	Seacat Conductivity and Temperature Recorder
ADCP ###	SIO Acoustic Doppler Current Profiler
Bio Acoustic	Tracor Science Applications Bio Acoustic Instrument
USC MVMS ######	University of Southern California Multi-Variable Moored System
LD MVMS ######	Lamont Doherty Earth Observatory Multi-Variable Moored System
MTR-####	WHOI Temperature Recorder

The design of the WHOI surface mooring took into consideration the high winds and sea state conditions expected during the monsoons. It is believed that the static and dynamic loads that the heavily instrumented WHOI surface mooring would experience, would be of such magnitude and duration that conventional designs used successfully in the past in more benign environments would not last in the Arabian Sea. This is because the dynamic loading may be so severe that ultimate strength considerations are superseded by the fatigue properties of the standard hardware components.

As part of the design process cyclic fatigue tests were conducted on all in line mooring components. Component selection was based on the test results. Shackles used on the WHOI mooring were shot peened to improve their fatigue endurance. Weldless endlinks replaced previously used weldless sling links based on their superior performance in the fatigue tests. Vector measuring current meter (VMCM) cages were gussetted and welds redone to meet new specifications established during the cyclic fatigue testing. More information about the design effort and cyclic fatigue tests can be found in Trask and Weller, 1995.

B. WHOI Instrumentation

A total of 36 recording instruments with 94 sensors were deployed on the WHOI Arabian Sea 2 surface mooring. There were two meteorological systems, nine current meters (four with bio-optical sensors), 18 temperature data loggers, five conductivity recording instruments, one tension recorder and one bio-acoustic instrument. Appendix 4 has a complete listing of all WHOI instrumentation deployed during TN 40 and TN 46. For each instrument type the listing shows the instrument serial number, the mooring on which it was deployed and the corresponding depth.

1. Meteorological Instrumentation

The WHOI discus buoy was outfitted with two separate meteorological packages. One system was a Vector Averaging Wind Recorder (VAWR) which logged and telemetered data from eight meteorological sensors. The second meteorological data recording system called IMET (Improved METeorological measurements) logged data from nine meteorological sensors. A third instrument made an independent measurement of relative humidity and temperature and recorded the data internally. All three systems are described in detail below.

a. Vector Averaging Wind Recorder

One of the two meteorological units mounted on the 3-meter discus buoy was a vector averaging wind recorder (VAWR), which is configured to measure wind speed, wind direction, short-wave radiation, long-wave radiation, relative humidity, barometric pressure, air temperature, and sea surface temperature. Recording to a digital cassette, the VAWR wrote data to tape every 7.50 minutes. Table 4 shows the type of sensors used for the meteorological measurements and the sampling scheme. Data from the VAWR was telemetered via satellite back to WHOI through Service Argos. The VAWR Argos transmitter has three PTT ID numbers for data transmission, one of which is used for obtaining position information. The standard temperature range typically used in the VAWR is 0 to 30°C. This range was modified to be 0 to 35°C for the Arabian Sea experiment due to the expected high temperatures. The VAWR sea surface temperature (SST) sensor was mounted on the bridle at a depth of approximately 1 meter. A continuous length of cable was run from the VAWR to the buoy deck and then down to the bridle mounted SST sensor via an external aluminum pipe mounted on the side of the buoy to protect the cable. This method eliminated the need for multiple bulkhead connectors which can affect the temperature reading. Details of the VAWR configuration can be found in Trask *et al.* 1995b.

b. Improved Meteorological System — IMET

The IMET system for the Arabian Sea WHOI Central buoy consists of nine IMET sensor modules. Table 5 details IMET sensor specifications. The modules measure the following parameters:

1. Relative humidity with temperature,
2. Barometric pressure,
3. Air temperature (RM Young passive shield),
4. Air temperature (aspirated shield),
5. Sea surface temperature,
6. Precipitation,
7. Wind speed and direction,
8. Short wave radiation,
9. Long wave radiation.

The data logger for the system is based on an Onset Computer Corp. Model 7 Tattletale computer with hard drive, also configured and programmed with power conservation in mind. An associated interface board ties the Model 7 via individual power and RS-485 communications lines to each of the 9 IMET modules.

Table 4: VAWR Sensor Specifications

Parameter	Sensor Type	Nominal Accuracy	Comments
Wind Speed	R.M. Young 3-cup 3-cup Anemometer	+5% +/-2%	Vector -averaged Note 1
Wind Direction	Integral vane w/vane follower	+/- 1 bit 5.6 degrees	Vector-averaged WHOI/EG&G
Insolation	Pyranometer Eppley 8-48	+/-3%	Averaged of reading
Longwave Radiation	Pyrgeometer Eppley PIR	+/- 10%	
Thermopile	PIR		Averaged
Body Temp.	10K @ 25°C		Note 2
Dome Temp.	10K @ 25°C		Note 3
Relative Humidity	Variable Dielectric Conductor Vaisala Humicap 0062HM	+/- 2% RH	3.515 sec. Sample Note 4
Barometric Pressure	Quartz crystal Digiquartz Paroscientific Model 215, 216	+/- 0.2 mbars wind < 20 m/s	2.636 sec. Sample Note 4
Sea Temperature	Thermistor Thermometrics 4K @ 25°C	+/-.005°C	Note 5
Air Temperature	Thermistor Yellow Springs #44034 5K @ 25°C	+/- 0.2°C wind > 5 m/s	Note 6

Notes:
1. Over estimation of wind speed is characteristic of cup anemometers.
2. LWR body temperature is measured during the third quarter of the recording interval, for one quarter of the record time. Error associated with solar heating is not included in accuracy.
3. LWR dome temperature is measured during the fourth quarter of the recording interval, for one quarter of the record time.
4. Relative Humidity and Barometric Pressure are burst samples taken in the middle of the recording interval.
5. Sea temperature is measured during the first quarter of the recording interval, for one quarter of the record time.
6. Air temperature is measured during the second quarter of the recording internal, for one quarter of the record time. Error associated with solar heating is not included in accuracy.

Table 5: IMET Sensor Specifications.

Parameter	**Sensor**	**Nominal Accuracy**
Air Temperature	Platinum Resistance Thermometer	+/-.25°C
Sea Temperature	Platinum Resistance Thermometer	+/-.005°C
Relative Humidity	Rotronic MP-100F	+/- 3%
Barometric Pressure	Quartz crystal AIR DB-1A	+/- .5 mbar
Wind Speed and Wind Direction	R.M. Young model 5103 Wind Monitor	-3% (speed) +/- 1.5° (dir)
Short-wave Radiation	Temperature Compensated Thermopile Eppley PSP	+/- 3%
Long-wave Radiation	Pyrometer Eppley PIR	+/- 10%
Precipitation	R.M. Young Model 50201 Self siphoning rain gauge	+/- 10%

Notes:

The logger polls all modules at one minute intervals (takes several seconds) and then goes to low power sleep mode for the rest of the minute. Data is written to disk once per hour.

The air temperature, sea surface temperature, barometric pressure, relative humidity, long wave radiation and precipitation modules take a sample once per minute and then go to low power sleep mode for the rest of the minute.

The short wave radiation module takes a sample every 10 seconds and produces a running one minute average of the six most recent samples. It goes to low power sleep mode between 10 second samples.

The vane on the wind module is sampled at one second intervals and averaged over 15 seconds. The compass is sampled every 15 seconds and the wind speed is averaged every 15 seconds. East and north current components are computed every 15 seconds.

Once a minute the logger stores an average east and north component that is an average of the most recent four 15 second averages. In addition average speed from four 15 second averages is stored, along with the maximum and minimum speed during the previous minute, average vane computed from four 15 second averages, and the most recent compass reading.

c. Stand Alone Relative Humidity / Temperature Instrument

A self contained relative humidity and temperature instrument was mounted on the tower of the WHOI discus buoy. This instrument, developed and built by members of the Upper Ocean Processes Group, takes a single point measurement of both relative humidity and temperature at a desired record interval. The sensor used is a Rotronics MP-100. The relative humidity and temperature measurements are made inside a protective Gortex shield. The logger is an Onset Computer Corp. model 4A Tattletale with expanded memory to 512K. The unit is powered by its own internal battery pack. The recording interval was set to 3.75 minutes for the Arabian Sea Experiment.

The height (and depth) of the buoy and bridle mounted instrumentation can be found in Table 6.

d. WHOI Shipboard Meteorological System

Following the deployment of a surface buoy and prior to its recovery it is a common practice to position the ship approximately .25 miles downwind of the buoy so that shipboard meteorological observations can be made and compared with the data collected by the buoy. While close to the buoy its Argos transmissions can be received, decoded and compared with the shipboard observations. The comparison of data provides a means to check that the buoy mounted sensors have not been damaged during deployment. Similarly if a sensor is damaged during recovery it may not be able to be recalibrated. If accurate shipboard observations are made prior to recovery it provides a means to evaluate the sensor's performance at the end of the deployment.

An independent meteorological data recording system was mounted to the jackstaff of the R/V *Thomas Thompson* for use during cruise number 52. The package recorded wind speed and direction, air temperature, relative humidity, and barometric pressure sensors. The relative humidity/air temperature sensor is a Rotronic MP-100 sensor that is aspirated to provide values uncontaminated by solar heating. The sensor is the same as is used in the IMET relative humidity module and the stand alone relative humidity with temperature instrument. The wind sensor is an R.M. Young propeller anemometer, also used in the IMET wind module.

Table 6: Sensors mounted on the WHOI Arabian Sea 2 surface buoy deployed from April 1995 to October 1995.

Parameter	Sensor ID	Elevation relative to buoy water line (meters)	Measurement Location
VAWR	V720WR		
Air Temp	Therm. 5854	2.7	Edge of 3rd plate from top
Relative Hum	V-029	2.72	Edge of 3rd plate from top
Barom. Press	S/N 44147	2.76	Center of port
Wind Speed	V720WR	3.34	Center of cups
Wind Direction	V720WR	3.07	Mid Vane
Short Wave	S/N 21972	3.41	Base of dome
Long Wave	S/N 28459	3.41	Base of dome
Sea Temp	Therm. 5568	-0.92	End of probe
IMET	Logger No. 228		
Air Temp	TMP 105	2.76	Edge of 3rd plate from top
Relative Hum	HRH 108	2.79	Edge of 3rd plate from top
Barom. Press	BPR 106	2.86	Center of port
Wind Speed	WND 111	3.25	Prop Axis
Wind Direction	WND 111	3.25	Prop Axis
Short Wave	SWR 104	3.41	Base of dome
Long Wave	LWR 103	3.42	Base of dome
Precipitation	PRC 108	3.12	Top of Funnel
Sea Temp	SST 006	-0.89	End of probe
Aspirated Air Temp	TMP 106	2.19	Openning of port
Stand alone RH w/ temp	005/27439	2.98	Edge of 3rd plate from top
Seacat	928	-1.42	At Temp Probe
Dissolved Oxygen	60	-1.42	Sensor end
Temperature Recorder	3291	-0.18	Thermistor end
Temperature Recorder	3299	-0.42	Thermistor end
Temperature Recorder	3280	-0.93	Thermistor end
Temperature Recorder	3263	-0.14	Thermistor end
Temperature Recorder	3274	-1.92	Thermistor end
Temperature Recorder	3271	-2.42	Thermistor end
Tension Cell	43845		Base of bridle

(-) indicates distance below buoy deck
Nominal distance between buoy deck and water line is .38 meters

Barometric pressure is measured with a Rosemount type 1201. Prior to the WHOI mooring recovery 4 hours of meteorological observations were made using the WHOI and ship's meteorological sensors.

2. Subsurface Instrumentation

The measured water line for the Arabian Sea 1 and 2 buoys was .38 meters below the buoy deck. Figure 5 illustrates the location of the subsurface sensors attached to the discus bridle.

a. Buoy Tension Recorder

Buoy tension was measured at the base of the buoy bridle using a D. J. Instruments Co. tension cell and was recorded using an Onset Computer Corp. Model 6 Tattletale. The tension cell was rated from 0 to 10,000 pounds. The sampling rate for tension in a 12 hour period beginning at 0000 UTC and 1200 UTC is as follows:

45 minutes of 4 Hz tension
15 minutes of 20 second max/min/average of 4 Hz tension
11 hours of 20 second max/min/average of 4 Hz tension

This is repeated every 12 hours for a 24 hour cycle. The data is then stored to a hard disk on the Tattletale.

b. Subsurface Argos Transmitter

An NACLS Inc. Subsurface Mooring Monitor (SMM) was mounted upside down on the bridle of the discus buoy as a backup recovery aid in the event that the mooring parts and the buoy flips upside down.

c. SEACAT Conductivity and Temperature Recorders

There were five Seabird Inc. Seacat conductivity and temperature recorders deployed on the WHOI surface mooring. The shallowest Seacat sn. 0928 was mounted directly to the bridle of the discus buoy at a depth of 1.42 m. The other four were mounted on in-line tension bars and deployed at 100, 150, 200 and 250 meters depth. The serial numbers for these Seacats, respectively were 0927, 144, 0929, 142. Following recovery of these Seacats, a post calibration time mark was done 21 October 95 between 2:23 and 2:41 UTC. The record rate for these instruments was set at 300 seconds.

UOP Arabian Sea Discus
Bridle Configuration

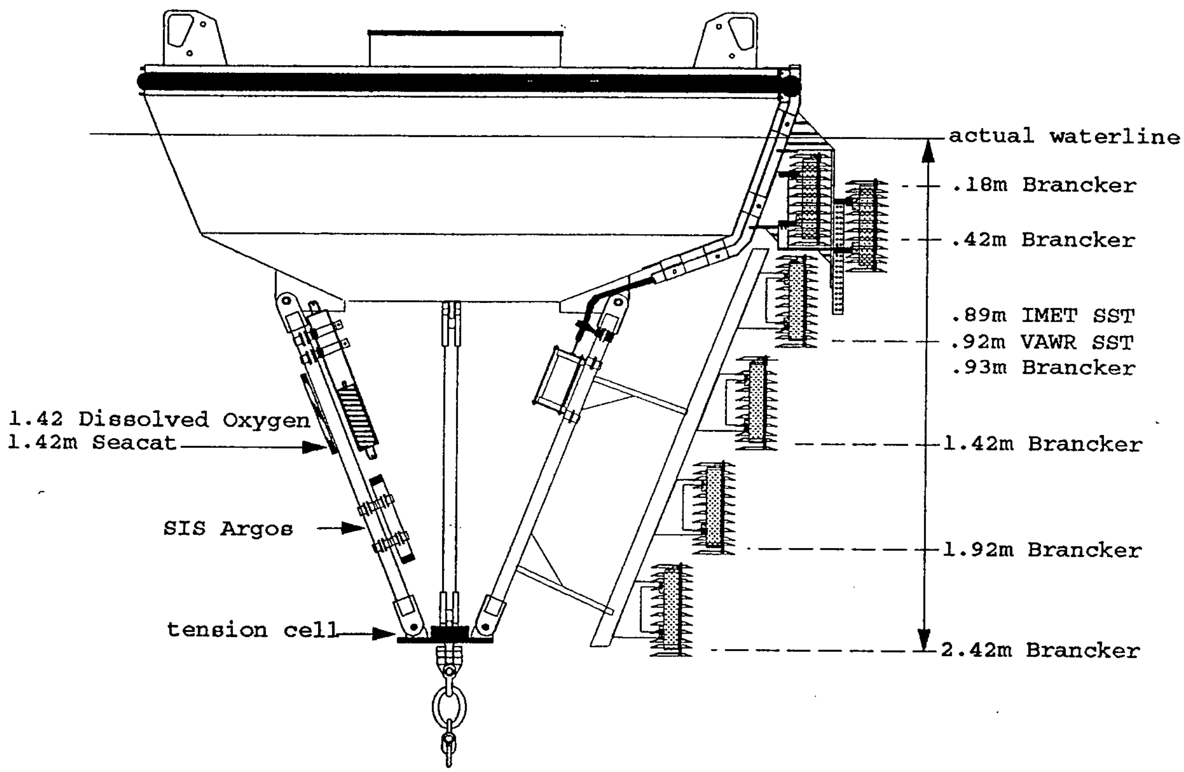

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Figure 5: Near-surface temperature array on the WHOI discus buoy.

The tension rods that were recovered during the first Arabian Sea cruise showed signs of low oxygen corrosion along the weldment where the Seacat attachment clamp and the tension bar were welded. For the second deployment, threaded barrel anodes were secured to the 316 stainless steel bolts which tightened attachment clamps to the instrument, in the hope that the anodes would reduce stainless corrosion. The tension rods from the second deployment showed no visible signs of corrosion.

d. Dissolved Oxygen Sensor

A LDEO self powered internally recording dissolved oxygen instrument was mounted to the buoy bridle at 1.42 meters depth. The sensor was recovered and had a full data set which was transferred to disk for later analysis.

e. Brancker Temperature Recorders

The Brancker Temperature Recorders are a self recording single point temperature logger. The operational temperature range for this instrument is -2° to 34°C.

A total of 18 Brancker temperature loggers were deployed on the discus mooring. Six were attached to the buoy in a near surface temperature string, with depths ranging from .18 to 2.42 meters. The other 12 Branckers were dispersed on the mooring at depths from 4.5 to 300 meters. Figure 4 (mooring schematic) lists the depths where Branckers were located.

Bio-fouling was apparent on the Branckers located between the surface and 20 meter depth. The extent of fouling was minimal compared to the heavy fouling that was found on the discus mooring from the first deployment. All Brancker battery voltages were at an acceptable level. All the Branckers had full data buffers with the exception of the 72.5 m depth instrument (sn. 3699) which had a 7% data buffer. Upon inspection of this instrument it was found that the screw securing the grounding strap was loose which allowed the power board to shift in the instrument housing causing the failure.

Two UOP Branckers were deployed on each of the University of Washington PCM moorings. Both moorings had one mounted on the top sphere at approximately 20 meters depth and the other was at 250 meters depth.

The 20 m Brancker (sn.3279), recovered from the failed PCM north mooring, was found to have a full data buffer as did the 20 m Brancker on the southern PCM mooring (sn.3835). The

250 m deep instrument on both the Northern and Southern PCM moorings (sn.2541 and sn.2533 respectively) also had full data buffers.

f. Miniature Temperature Recorder (MTR)

A single Pacific Marine Environmental Lab (PMEL), Miniature Temperature Recorder (MTR) was mounted at 3.5 meters depth in-line on the mooring.

The MTR (sn.3250) had a full data buffer and the battery voltage was good. The sample rate for this instrument was 7.5 minutes. A post time mark was done on 21 October 95 01:38 - 2:16 UTC.

Several goose neck barnacles were found attached to the inside of the recorder bracket.

g. WHOI Vector Measuring Current Meters

Five WHOI Vector Measuring Current Meters (VMCM) were deployed on the WHOI surface mooring at 5, 15, 25, 45, and 55 meters depth. The five surface mooring VMCMs recorded data on digital cassette every 3.75 minutes. A description of how each parameter is sampled is provided in Appendix 5.

Upon recovery the following observation were made for the five WHOI VMCMs.

VM-050 (5 meters) had severe gooseneck barnacles on the cage clamps and ends of cage and case end cap. One gooseneck barnacle was found on the lower rotor. Rotors spun freely.

VM-030 (15 meters) had a small amount of gooseneck barnacles on cage bands. Rotors spun freely.

VM-034 (25 meters) had no gooseneck barnacles on case or cage, but did have a hairy sea slime adhered to the instrument case. Rotors spun freely.

VM-003 (45 meters) had hairy sea slime on the non-antifouled ends of cage. Rotors spun freely.

VM-014 (55 meters) had no fouling on case or cage. Rotors spun freely.

A down-cruise procedure was completed on each VMCM recovered. All VMCMs pulled full cassette tape and had good battery voltages. The rotor spin down times were excellent. One VMCM (VM-050) would not communicate via 20 m A sail.

Five WHOI VMCMs were also deployed at 300, 500, 750, 1500 and 3000 meters on the University of Washington southern PCM mooring.

VM-016 (300 meters), VM-018 (500 meters), VM-021 (750 meters), VM-025 (1500 meters) and VM-038 (3000 meters) were free of gooseneck barnacles and hair algae. These VMCM's with the exception of the VM-038, which had a flooded sting, had free spinning rotors. Details about the VMCM bearings and propeller blade material can be found in Trask and Brink (1993).

h. USC — Multi-Variable Moored System

University of Southern California, deployed two Multi-Variable Moored Systems (MVMS) units at 35 meters and 80 meters.

The 35 meter MVMS sensors were functional with excellent data return including VMCM current rotor counts and vectors, compass, temperature, Biospherical PAR & 683nm sensors, USC dissolved oxygen, dissolved oxygen temperature, Sea-Bird conductivity, Sea Tech stimulated fluorometer, and Sea Tech transmissometer. On June 21 the mount that supported the PAR and 683nm sensors was "broken off" (cause unknown). On recovery the PAR cable was wrapped loosely around the sting assembly interfering with the lower rotor. The lower rotor had one propeller blade missing. A light algae or hydrozoan growth covered the package and sensors.

The 80 meter MVMS sensors were functional with excellent data return including VMCM current rotor counts, vectors, compass, temperature, Biospherical PAR & 683 nm sensors, USC dissolved oxygen, dissolved oxygen temperature, Sea-Bird conductivity, Sea Tech stimulated fluorometer, and Sea Tech transmissometer. On July 19th the PAR and 683 nm sensors mount was "broken off" (cause unknown). On recovery two propeller blades were found missing on the upper rotor. A few small gooseneck barnacles were present on the package. Fouling on sensors was minimal.

i. LDEO — Multi-Variable Moored System

Lamont Doherty Earth Observatory, had two Multi-Variable Moored Systems (MVMS) at 10 and 65 meters. The 10 m MVMS returned good data. All sensors were working at the time of recovery. The PAR sensor diffuser was missing, however. The data records indicated that the diffuser was lost on 16 September, 45 days before recovery. The PAR sensor data showed that there was shading from the discus buoy for samples collected during the time period of local noon. Optical sensors were partially covered and or obstructed with gooseneck barnacles at the time of recovery. Data records from the transmissometer indicated severe fouling after year day 160, (50 days after deployment) while fluorometer data showed fouling after year day 200. The 683 light sensors showed fouling after year day 180. Current meter data return was good. Peak currents occurred around year day 230 when a -80 cm/sec northern component was recorded. Compass data showed mild orientation of the package to 200 degrees magnetic between year days 160 and 230. Some of the rotor blades were recovered broken although the records do not seem to indicate a change in performance. Corrosion was less severe than the October 94 to April 95 deployment.

The MVMS at 65 meters also showed good data return. All sensors were working at the time of recovery. The PAR sensor diffuser (white ball) was missing and records indicate that the diffuser was lost 20 days before recovery. The Optical sensors were covered with brown algae. The records from the transmissometer and fluorometer indicate severe fouling after year day 250, while optical signals seem reasonable prior to that time. Current meter data return was good. Peak currents occurred around year day 210 when a -60 cm/sec north component and a +60 cm/sec east component were recorded. Compass data showed mild orientation of the unit to 100 degrees magnetic, between year day 200 and 250. Some of the rotor blades were broken although the records did not indicate a change in their performance up to the end of the deployment.

j. LDEO — Spectral Radiometer 65 meters

The 65 meter MVMS was outfitted with a Spectral radiometer. This was the first long term deployment of this type of instrument. The instrument returned an excellent data record. Irradiation data in all 32 wavelengths correlated with corresponding data from the PAR and 683 sensors from the 65 m MVMS. The optical window had only mild biofouling. Approximately 1.5 cm^2 out of the total 16 cm^2 optical window was covered by small barnacles possibly due to the smooth surface characteristic of the material, Acrylite, used in the diffuser.

k. Tracor Applied Sciences Bio-Acoustic Instrument

A Tracor Applied Sciences bio-acoustic transceiver array measuring back scattering at multiple frequencies to give zooplankton estimates by size distributions was deployed on the WHOI surface mooring at 40 meters and on the southern PCM mooring at 215 meters.

Both bio-acoustic transceivers were found to be flooded following recovery.

l. SIO — Surface Mooring Instrumentation

The ADCP's on each of the SIO moorings functioned properly for the entire deployment with 100% data return. The northern SIO mooring had ten Brancker temperature loggers, of which 9 functioned with 100% data stored. One of the loggers was recovered with only the instrument case attached to the mooring wire. It has not been determined why the electronics had separated from its housing. There were also ten Branckers on the southern SIO mooring. Out of these ten, five Branckers were lost. Upon recovery it was found that the two 1/4" x 20 stainless bolts that secured the logger to the 3/8" wire rope had sheared off. It is suspected that the bolts failed due to being over tightened prior to deployment. The 5 remaining Branckers had full data buffers.

m. UW — Profiling Current Meter

The recovered southern PCM (sn.8-1) had 1042 profiles with 100% data stored. The northern PCM (sn.07) was lost.

Section 3: Cruise Chronology

The R/V *Thomas Thompson* cruise number 52 (TN052) departed Muscat, Oman, on 13 October 1995 at 1000 UTC. The purpose of the cruise was to recover three surface and two subsurface moorings as part of the Arabian Sea Experiment. This was the third of three cruises planned for the experiment.

Expendable bathythermograph (XBT) data and CTD data were collected while in transit to the site and at mooring locations. The XBT data was collected hourly while en route beginning at 0408 UTC, 14 October 1995, and the last XBT was dropped at 1659 UTC, 24 October 1995. A total of 151 XBT casts were taken. Six CTD casts were during the cruise. These profiles were done in conjunction with each mooring site.

Deck plans depicting how the mooring buoys were moved on the ship's deck during the cruise can be found in Appendix 7. These deck plans were drawn prior to departure on the cruise and used as the guide for deck operations.

Northern PCM Mooring Recovery, 16 October 1995

On 16 October at 0210 UTC, the release of the remaining section of the failed northern PCM moorings was fired. Figure 6 illustrates the mooring section recovered. The syntactic sphere reached the surface in 19 minutes. The ship's small boat was lowered and maneuvered to the floating 60" diameter sphere. A UOP buoy pick up line tied to a tow line was secured to the lifting bail on the sphere. The small boat then began to tow the sphere and attached mooring towards the R/V *Thompson*, which was positioned 2 miles down wind. When the small boat arrived at the stern of the ship, a heaving line attached to a long tag line was thrown from the ship to the small boat. The tow line was untied from the small boat and retied to the end of the tag line. This tag line was pulled in through the ship's stern A-frame until the bitter end of the UOP buoy pick up pennant was raised up to the edge of the ship's transom. A Lebus winch tag line reeved through the ship's trawl block hanging from the center of the A-frame was shackled to the lifting pennant. The Lebus tag line lifted the sphere up so that the equator of the sphere was parallel to the transom of the ship. Two air tugger hauling lines were attached at opposing fair lead bails on the sphere. With the tugger lines in place, the sphere was lifted up 6 ft above the deck level. The ship's A-frame was swung inboard. A 1/2" chain grab attached to a 3/4" nylon stopper line was hooked onto the 1/2" chain shot shackled to the bottom of the sphere. The stopper was drawn up tight and secured to a deck cleat. The sphere was lowered into a cradle and secured to the deck. The USC, Multi-Variable Moored System (MVMS) was recovered in

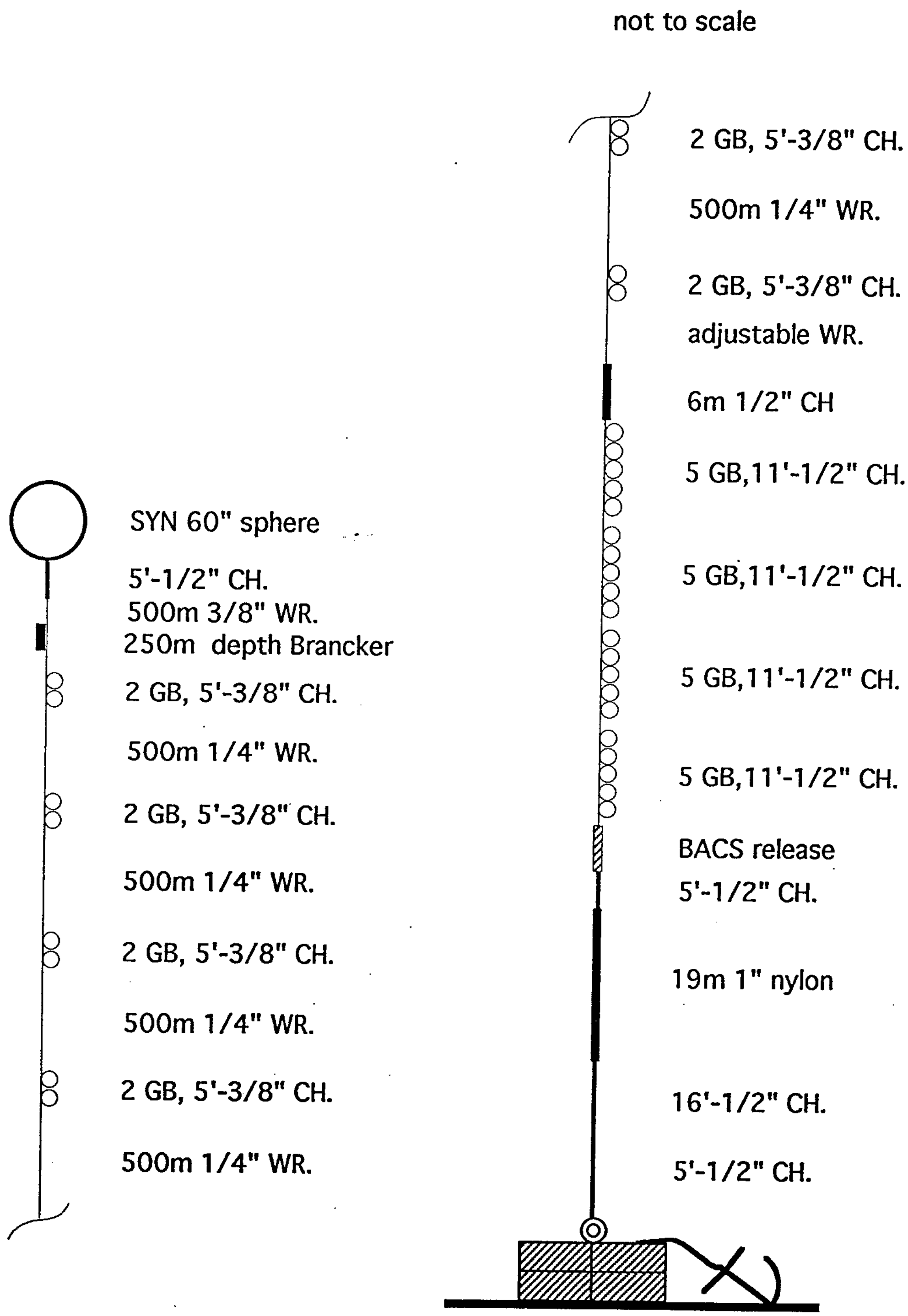

Figure 6: Schematic remainder of PCM northern mooring.

the same manner using the A-frame, Lebus winch and stopper line. The ship's HIAB crane, with a WHOI Gifford block attached to the end of its boom, was then positioned over the center of the A frame. The end of the tag line reeved through the Gifford block was shackled to the stopped-off end of the mooring wire. The tension was taken up by the Lebus winch and the stopper line holding the mooring wire was eased off and removed. The remainder of the mooring was recovered using the HIAB crane, Lebus and deck stopper line without problem or mishap. Mooring operations were completed by 0629 UTC.

Southern PCM Mooring Recovery, 17 October 1995

At 0212 UTC, the upper acoustic release was fired allowing the top sphere, guide line and PCM to ascend to the surface. Figure 7 illustrates this mooring. The top sphere was spotted from the ship and the small boat was dispatched to tow the top 42" steel sphere towards the stern of the ship. This sphere was recovered using the same procedure described previously for the recovery of the northern PCM 60" sphere. The guide line and PCM were retrieved using the HIAB, Gifford block and Lebus winch in the following manner. The winch tag line was attached to the top termination of the guide line and the Lebus winch hauled in 176 meters of guide line onto a storage reel. Once the PCM, positioned at the end of the guide line, had reached the surface a safety line was secured around the sensor stalk of the instrument. This line was made from a 3/4" nylon tag line with one of its ends tied into a bowline onto itself to form a noose. It was tied around the hanging guide line outboard of the Gifford block and allowed to fall down around the PCM's sensor stem and be drawn up tight. This line was used as a precaution in the event that the guild line parted while lifting the PCM out of the sea. The guide line was hauled in raising the PCM clear of the deck. The HIAB crane then swung the PCM inboard. A storage cage was secured around the PCM. The guide line was off spooled from the Lebus storage reel and coiled into a figure eight and secured to the PCM cage. It was 0305 UTC at the conclusion of this segment of the mooring operation.

The bottom section of the mooring was recovered in approximately three hours and followed the same procedures used in recovering the bottom section of the northern PCM mooring.

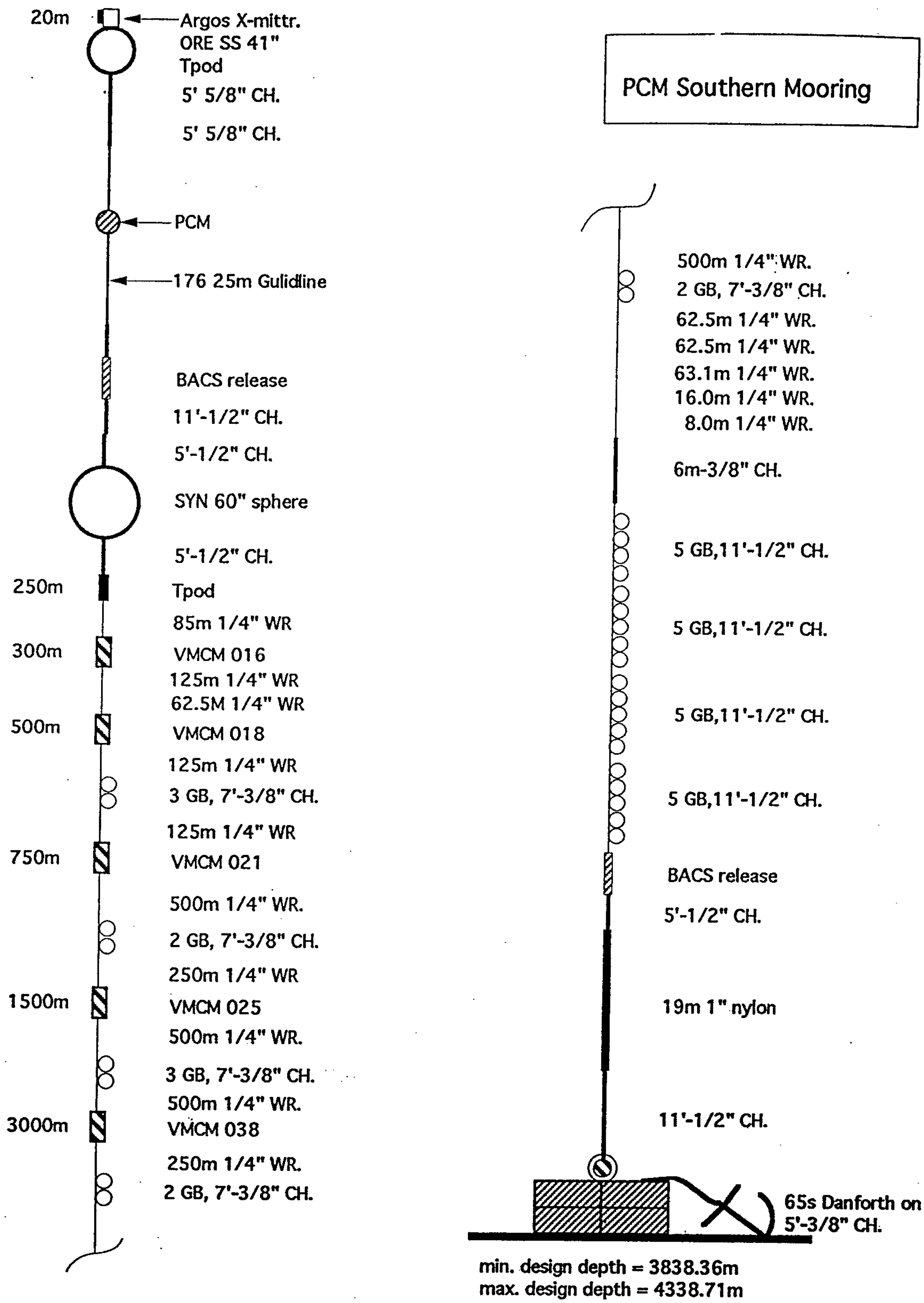

Figure 7: Schematic PCM southern mooring.

SIO Southern Mooring Recovery, 18 October 1995

The SIO southern mooring recovery commenced 18 October at 0200 UTC and was completed by 0730 UTC. Figure 8 illustrates the SIO southern mooring. Several attempts to release the acoustic release were made. The first attempt was tried with the ship .59 miles from the anchor site. Due to stratification in the mixed layer at this site, the acoustic release would not fire. The ship moved away an additional 5 miles. The release functioned normally releasing the mooring. The small boat attached a tow line to the toroid buoy and steamed down wind, stretching the mooring apart to keep it from tangling onto itself as the backup flotation at the end of the mooring reached the surface. The small boat cast adrift the toroid after approximately 40 minutes of towing. The glass balls connected to the end of the mooring surfaced .5 miles up current from the toroid. The small boat maneuvered towards the 42 floating glass balls and tied a tow line to the ball cluster. The R/V *Thompson* then slowly backed astern towards the small boat. The same procedure was used in connecting the Lebus tag line to the glass ball cluster as had been used for the recovery of the PCM's 60" syntactic sphere. Once the glass balls had been recovered, the remainder of mooring's nylon and wire rope was hauled in using the Lebus winch until there was approximately 50 meters of mooring wire separating the toroid and the ship. The mooring wire was cut and cast off, allowing the toroid to be adrift. The small boat was launched and proceeded to the drifting toroid and attached a tow line and pulled the toroid up along the port side, close enough to allow a UOP pick up pennant to be hooked onto the buoy's lifting bail. The free end of the pennant was hooked onto the 01 crane whip hook and the buoy was raised so that the hull was parallel to the deck of the ship.

Three air tugger hauling lines were attached to the tower, buoy deck and bridle. These lines controlled the rotation of the toroid's tower as it cleared the deck. A 1 1/2" nylon line bull rope with a 3/4" chain shackled to its end, was reeved around the ship's capstan and lead where the toroid's bridle would be secured on the deck. This line's function was to take the hanging mooring tension off the shackle connection between the 3/4" chain and the toroid bridle, to allow this shackle connection to be uncoupled. The toroid was raised so that the 3 ft of the 3/4" chain attached the apex of the buoy bridle was above the deck level. The bull rope was hooked 2 feet below the apex of the bridle and lowered onto the deck. The bull rope hauled on the 3/4" chain allowing the mooring tension between the hanging mooring and the toroid to go slack. The toroid was secured to the deck and unshackled from the mooring. The crane whip was unhooked and repositioned over the stopped off 3/4" chain. The crane whip hooked onto the free end of the stopped off 3/4" chain. The whip was raised and the bull rope removed. The 3/4" length of chain and the depressor weight were recovered. The remaining 50 meters of 3/8" wire rope were shackled to the depressor weight and manually recovered.

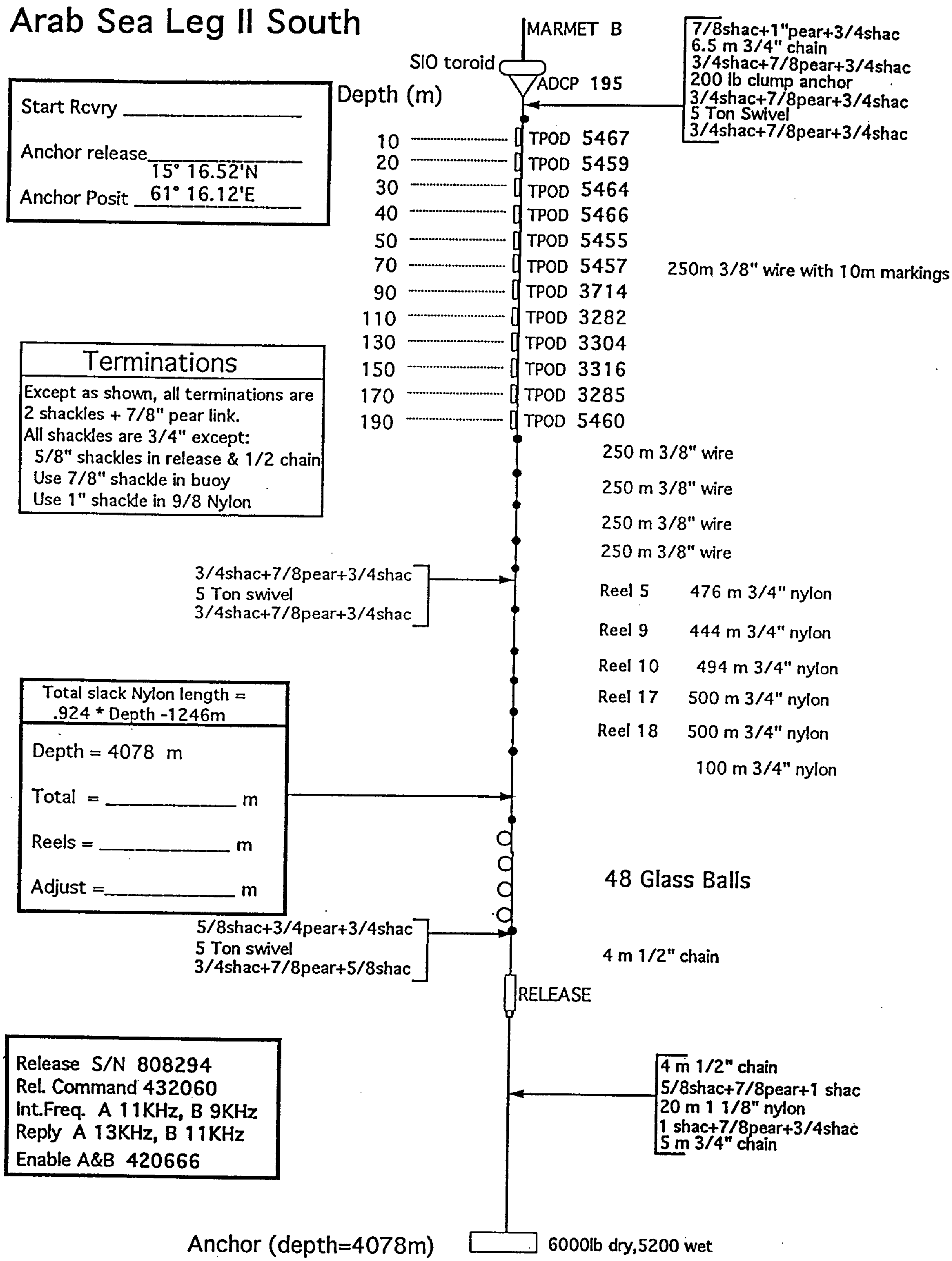

Figure 8: Schematic SIO southern surface mooring.

SIO Northern Mooring Recovery, 19 October 1995

The SIO northern mooring recovery commenced 19 October at 0200 UTC and was completed 0630 UTC. Figure 9 illustrates this mooring's configuration. The procedures for recovering the SIO southern were used in the recovery for SIO northern mooring.

WHOI Mooring Recovery, 20 October 1995

The WHOI mooring recovery commenced 20 October at 0545 UTC. Figure 4 illustrates the WHOI mooring design. The R/V *Thompson* maneuvered to a position 2 miles downwind of the mooring site. The ship's small boat was deployed and directed to attach a tow line onto the discus. The acoustic release was fired and confirmation was made that the mooring had been set adrift. The small boat was instructed to begin to tow the discus buoy downwind in an attempt to pull the buoy away from the ascending 82 glass ball cluster attached to the lower end of the mooring. Fifty minutes after firing the release the glass balls appeared on the surface, approximately 200 yards upwind of the discus buoy. The small boat released its tow from the discus and maneuvered to the glass ball cluster. A tow line was attached to the ball cluster. The small boat started to tow the ball cluster towards the stern of the ship. The R/V *Thompson* began to back up slowly towards the small boat. Once the small boat was positioned approximately 50 ft. from the ship's stern, the Lebus tag line which was reeved through a trawl block hanging in the A-frame was passed to the small boat. The tag line was then tied to the tow line. The tow line was cast off from the small boat. The Lebus winch began to haul in the tag line hauling up with it the ball cluster up out of the sea. Three air tugger hauling lines were secured to the suspended ball cluster in the A-frame. These lines were used to drag the ball cluster inboard, as the A-frame swung inboard. The next mooring component to be recovered was the 1 1/8" polypropylene line shackled to the glass ball cluster. The shackle coupling between this line and the ball cluster was tangled in the balls, making it difficult to remove safely. The polypropylene line that was hanging over the stern of the ship was stopped off using 5/8" tag line tied to the polypropylene line using a timber hitch knot. The tag line was cleated to the deck and the polypropylene line was cut. A bowline was tied on the free end of the polypropylene line. The Lebus tag line was removed from the A-frame trawl block and reeved through the Gifford trawl block which hung from the HIAB crane boom. The HIAB crane was used because it allowed for greater flexibility in controlling the angle of the mooring wire and line during the mooring recovery. The Lebus tag line was then shackled to the bowline and tension was slowly taken up on the winch. The tag line was untied, once the Lebus winch had started to haul in the polypropylene line. The polypropylene and nylon line was recovered and wound onto AR32 storage reels. The condition of these lines was very good. The wire rope was recovered and wound into coils for disposal ashore. The condition of wire as well was good. There were no signs of fish bite on the wire shots.

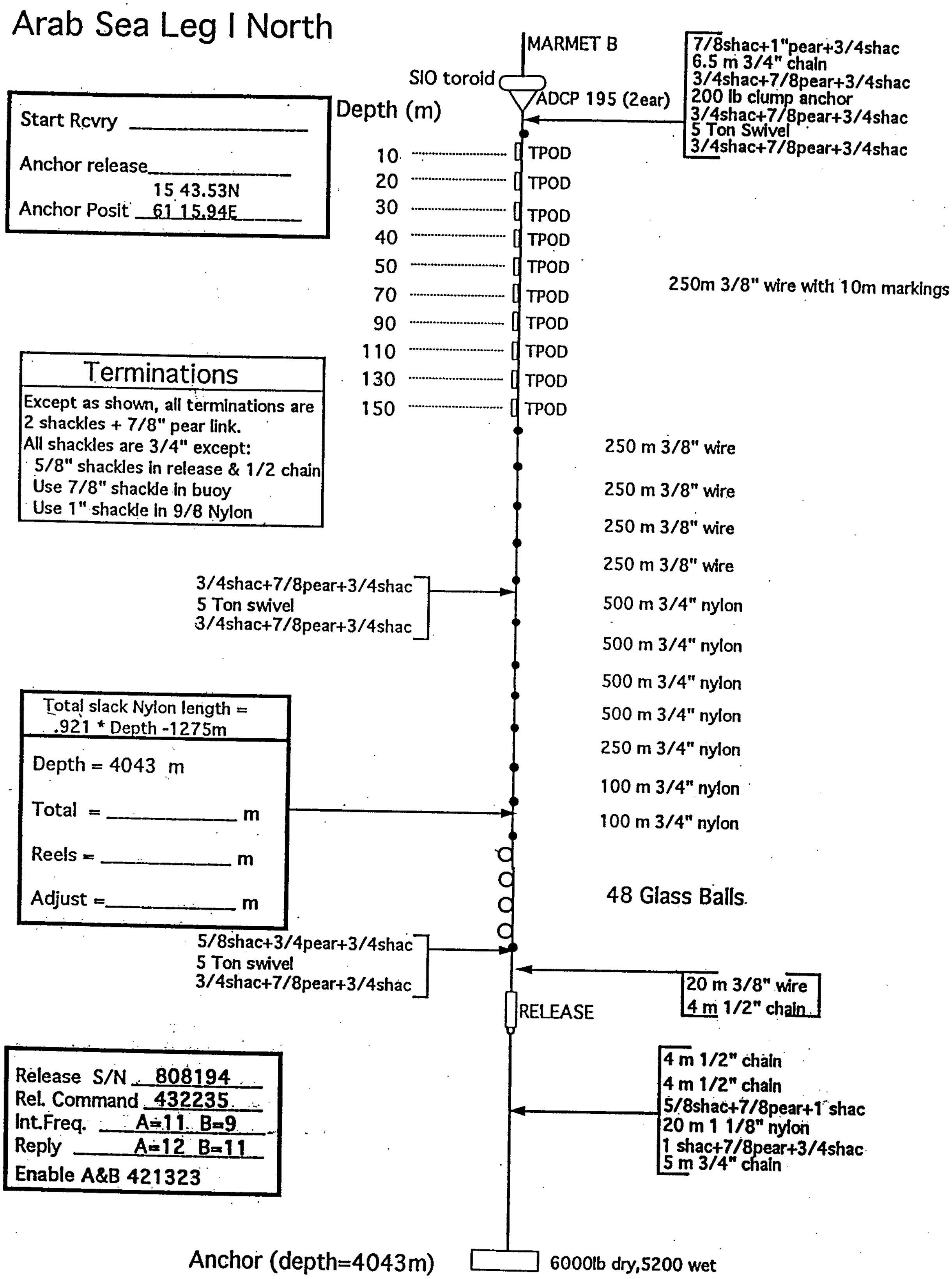

Figure 9: Schematic SIO northern surface mooring.

The mooring recovery operation was stopped at the junction between the top of the 35 meter MVMS and 7.25 meter length of 1/2" wire rope. The remainder of the mooring wire, subsurface instrumentation and discus buoy were recovered using the port side 02 crane in the following manner.

The R/V *Thompson's* small boat was lowered and maneuvered to the discus buoy. A tow line from the small boat was secured to the discus. The stopped off end of 7.25 meter wire rope was slipped over the stern and cast away, setting the discus adrift. The small boat then began to tow the discus around the stern of the ship along the port side towards the 02 crane. The discus was positioned alongside of the ship close enough to allow a WHOI pick up pennant to be hooked onto the discus pick up bail. Figure 10 details the discus lifting bail configuration. The free end of the pick up pennant was then hooked onto the 02 crane whip. The small boat tow line was then cast off. The crane whip was raised, lifting the discus out of the sea in order to bring the buoy's hull parallel to the ship's deck. Three air tugger lines were secured to the tower and buoy deck bails. These lines were used to control the rotation of the discus tower during the buoy lift. The discus was raised so that the apex of the bridle was 6 inches above the deck. A fourth air tugger line was attached to the bridle. A 3/4" chain grab shackled to a 1 1/2" bull rope was hooked to the .4m shot of 3/4" chain shackled below the discus bridle. The bull rope was reeved around the ship's capstan and tension was taken up. As the tension increased on the bull rope, the tugger line attached to the tower was brought under tension causing the tower to swing inboard. The 02 crane swung inboard slowly shifting the discus over the deck. The tension increased on the bull rope and the 02 crane lowered the discus to the deck. The now slack shackle junction between the apex of the discus bridle and .4 meter 3/4" chain was disconnected. The discus was lashed to the deck using chain lashings. The 02 crane was repositioned over the stopped off 3/4" chain with 8 meters of vertical boom extension. A 6 ft 10,600 lb. capacity Lift All sling was rigged in a basket hitch through the end link shackled to the free end of the stopped off 3/4" chain. This sling was the passed over the 02 crane whip hook. The whip was raised and the bull rope removed. The 5 and 10 meter VMCM were lifted up clear of the ship's deck. The bull rope was reattached to the end link shackled to bottom of the 10 meter VMCM. Tension was applied to the bull rope and the crane's whip was lowered. The VMCMs were disconnected and removed to an instrument staging area for preliminary inspection and evaluation. This procedure was repeated for recovery of the remainder of the mooring. The last mooring components were recovered at 0730 UTC.

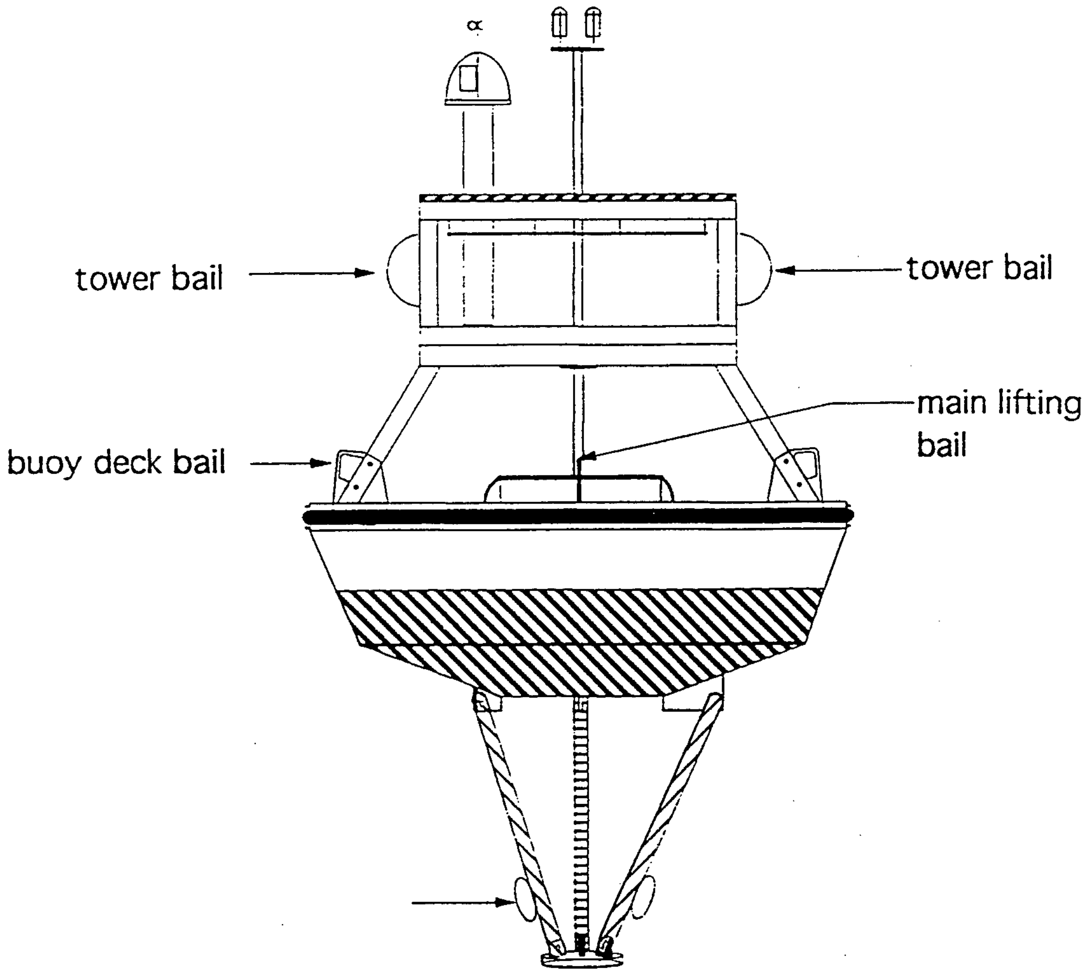

Figure 10: UOP Discus buoy bail configuration.

Acknowledgments

The captain and crew of the R/V *Thomas Thompson* deserve special thanks for their hard work and dedication in making TN 52 a total success. A ship is a good ship, only when there are highly skilled professionals to run her. We sincerely thank Nancy Brink, Mary Ann Lucas and Penny Foster for their help in preparing this report.

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Appendix 1: Cruise Participants — TN-052

Neil Bogue	University of Washington
Tony Burke	University of Washington
Charles Eriksen	University of Washington
Chris Kinkade	Lamont-Doherty Earth Observatory
Miguel Maccio	Lamont-Doherty Earth Observatory
Derek Manov	University of Southern California
Chris Martin	Scripps Institution of Oceanography
William Ostrom	Woods Hole Oceanographic Institution
John Paoli	Scripps Institution of Oceanography
Lloyd Regier	Scripps Institution of Oceanography
Daniel Rudnick	Scripps Institution of Oceanography, Chief Scientist
John Shillingford	C.S. Draper Laboratory
David Sigurdson	University of Southern California
Marcela Stern	Lamont-Doherty Earth Observatory
Margaret Sullivan	University of Washington
Jonathan Ware	Woods Hole Oceanographic Institution
Bryan Way	Woods Hole Oceanographic Institution
Robert Weller	Woods Hole Oceanographic Institution

Appendix 2: XBT Positions and Plots

One hundred and fifty-one XBTs were deployed during TN 052. The T-7 probes were purchased from Sippican Ocean Systems, Inc., in Marion, Massachusetts. The XBT data were logged using the shipboard data acquisition system. Figure A2-1 is a map showing the location of XBTs taken while enroute to the mooring site (outbound) and when returning to Muscat (inbound) at the end of the cruise. Table A2-1 lists the dates and positions of the outbound XBTs along with the corresponding bucket temperatures. Figures A2-2 through A2-4 show the outbound XBT temperature profiles in groups of 20. Each successive profile is offset by 1°C from the previous one. Table A2-2 lists the dates and positions of the inbound XBTs and Figures A2-5 through A2-9 show the temperature profiles from the inbound XBTs.

Fall '95 XBTs

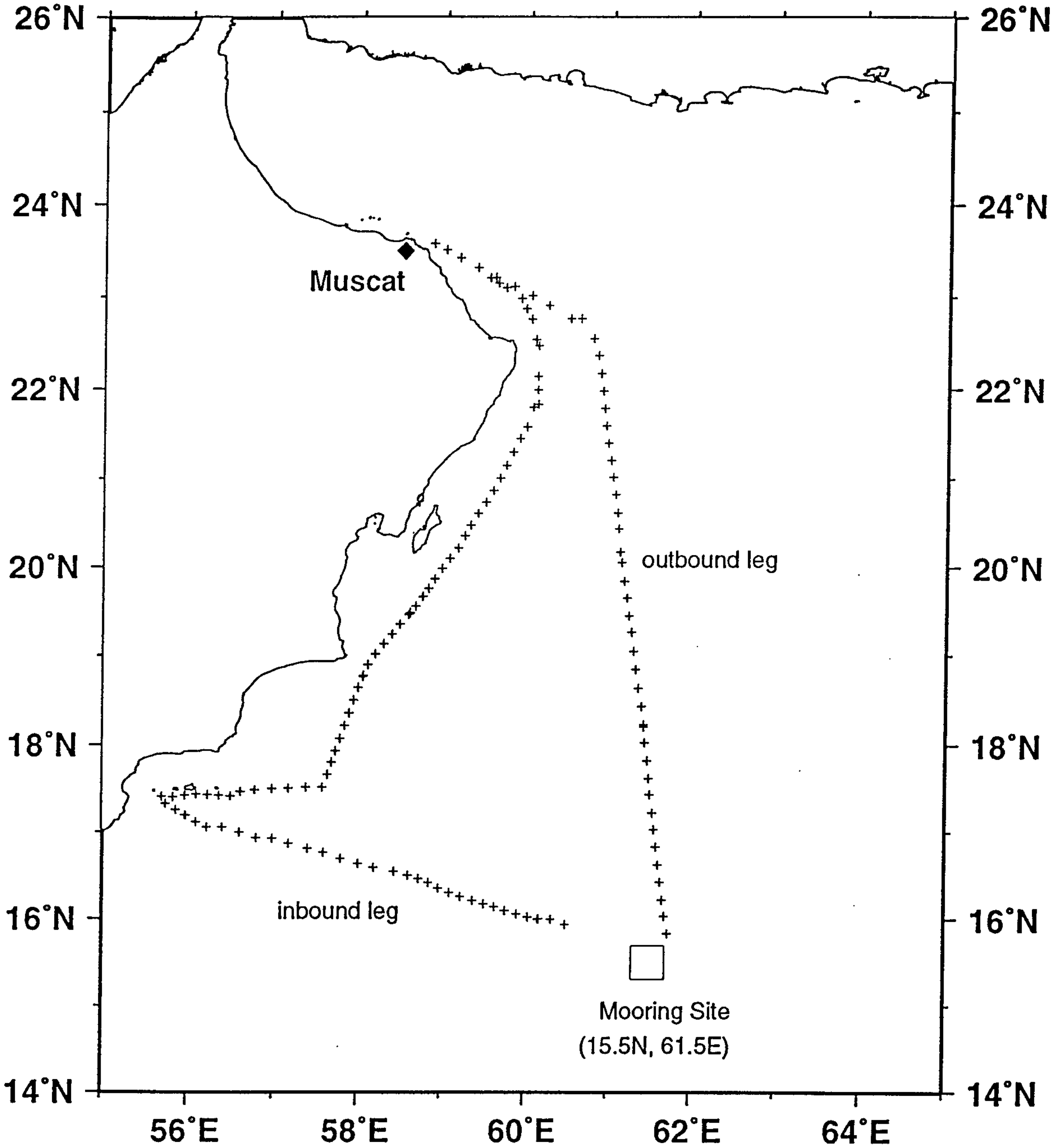


Figure A2-1: XBT positions.

Table A2-1: TT52 Outbound XBTs

XBT#	Date	Time (UTC)	Latitude (N)	Longitude (E)	SST (°C)	Comment
1	10/14/95	04:08:00	23°34.84'	58°51.58'	31.0	(0)
2	10/14/95	05:04:34	23°30.90'	59°00.28'	30.6	(1)
3	10/14/95	06:05:13	23°25.49'	59°10.24'	30.5	(2)
4	10/14/95	07:04:04	23°19.23'	59°22.97'	29.8	(3)
5	10/14/95	08:02:11	23°13.18'	59°35.91'	31.0	(4)
6	10/14/95	09:01:42	23°07.12'	59°48.94'	30.5	(5)bad
7	10/14/95	09:06:52	23°07.12'	59°48.94'	30.5	(6)
8	10/14/95	10:01:55	23°01.20'	60°01.85'	31.1	(7)
9	10/14/95	11:03:42	22°54.80'	60°14.23'	27.8	(8)bad
10	10/14/95	11:08:02	22°54.80'	60°14.23'	27.8	(9)
11	10/14/95	11:57:12	22°49.06'	60°25.26'	29.0	(10)bad
12	10/14/95	12:23:08	22°46.45'	60°30.23'	28.7	(11)
13	10/14/95	13:01:37	22°42.24'	60°37.57'	28.4	(12)
14	10/14/95	14:00:04	22°33.45'	60°47.06'	27.6	(13)
15	10/14/95	15:00:02	22°22.08'	60°50.52'	27.4	(14)
16	10/14/95	16:01:35	22°10.34'	60°52.55'	27.4	(15)
17	10/14/95	17:01:54	21°58.81'	60°54.22'	27.4	(16)
18	10/14/95	18:00:23	21°47.13'	60°55.46'	27.5	(17)
19	10/14/95	18:59:45	21°35.42'	60°56.63'	27.6	(18)
20	10/14/95	19:59:30	21°23.91'	60°58.34'	27.5	(19)
21	10/14/95	20:58:55	21°12.39'	61°00.19'	28.2	(20)
22	10/14/95	21:57:38	21°01.00'	61°01.93'	28.3	(21)
23	10/14/95	22:58:48	20°49.26'	61°03.83'	28.3	(22)
24	10/15/95	00:01:31	20°37.16'	61°05.34'	28.3	(23)
25	10/15/95	00:56:03	20°26.63'	61°06.24'	28.1	(24)
26	10/15/95	01:54:26	20°15.11'	61°07.15'	27.6	(25)
27	10/15/95	02:02:35	20°13.81'	61 °07.27'	27.6	(26)
	10/15/95	02:12:56	test probe			
28	10/15/95	02:17:15	20°10.52'	61°07.49'	28.1	
29	10/15/95	02:55:06	20°03.41'	61 °08.52'	27.9	
30	10/15/95	04:02:35	19°50.56'	61 °10.62'	27.6	
31	10/15/95	04:58:08	19°39.17'	61°12.64'	27.3	
32	10/15/95	05:58:37	19°27.19'	61°14.37'	27.5	
33	10/15/95	06:55:42	19°16.07'	61°16.15'	27.8	
34	10/15/95	07:58:20	19°03.28'	61°17.83'	27.8	
35	10/15/95	08:57:45	18°51.03'	61°19.58'	27.9	
36	10/15/95	10:00:25	18°38.29'	61°21.45'	27.8	
37	10/15/95	11:00:26	18°26.28'	61°23.61'	28.0	
38	10/15/95	12:02:03	18°13.77'	61°25.19'	28.3	
39	10/15/95	12:07:09	18°12.49'	61°25.34'	28.3	
40	10/15/95	13:00:58	18°01.76'	61°26.42'	28.0	
41	10/15/95	14:02:12	17°49.47'	61°28.07'	28.2	
42	10/15/95	15:02:02	17°37.13'	61°29.42'	28.1	
43	10/15/95	15:59:36	17°25.86'	61°30.26'	28.0	
44	10/15/95	17:00:18	17°13.36'	61°32.14'	27.8	

XBT#	Date	Time (UTC)	Latitude (N)	Longitude (E)	SST (°C)	Comment
45	10/15/95	17:59:13	17°01.65'	61°33.53'	27.5	
46	10/15/95	18:58:27	16°49.90'	61°34.95'	27.9	
47	10/15/95	20:01:07	16°37.70'	61°36.44'	27.9	
48	10/15/95	21:01:15	16°25.55'	61°38.18'	28.3	
49	10/15/95	22:01:48	16°13.39'	61°39.97'	28.0	
50	10/15/95	22:59:40	16°01.90'	61°41.64'	27.7	
51	10/16/95	00:00:13	15°50.04'	61°43.72'	27.7	

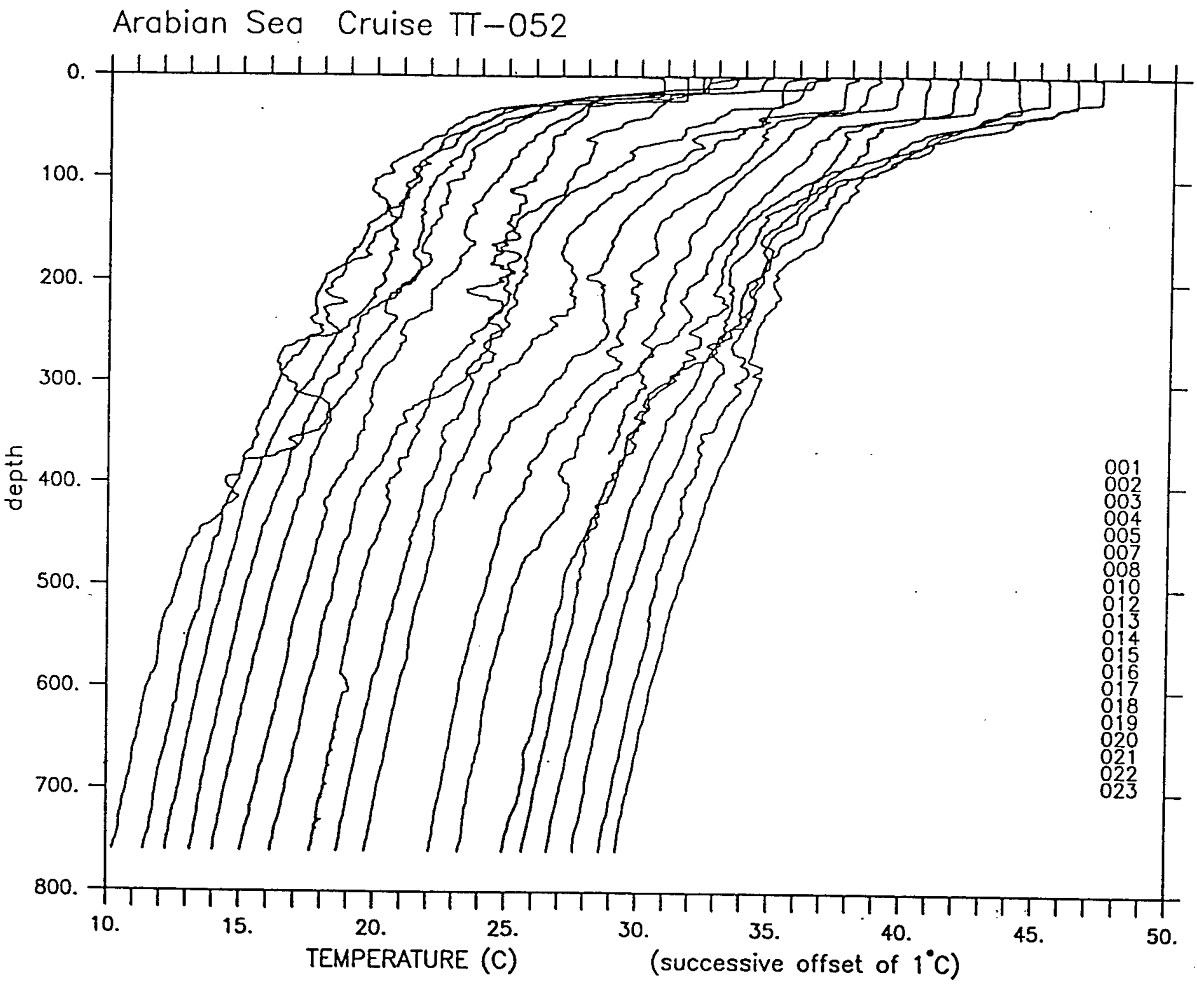


Figure A2-2: Outbound XBT overplot.

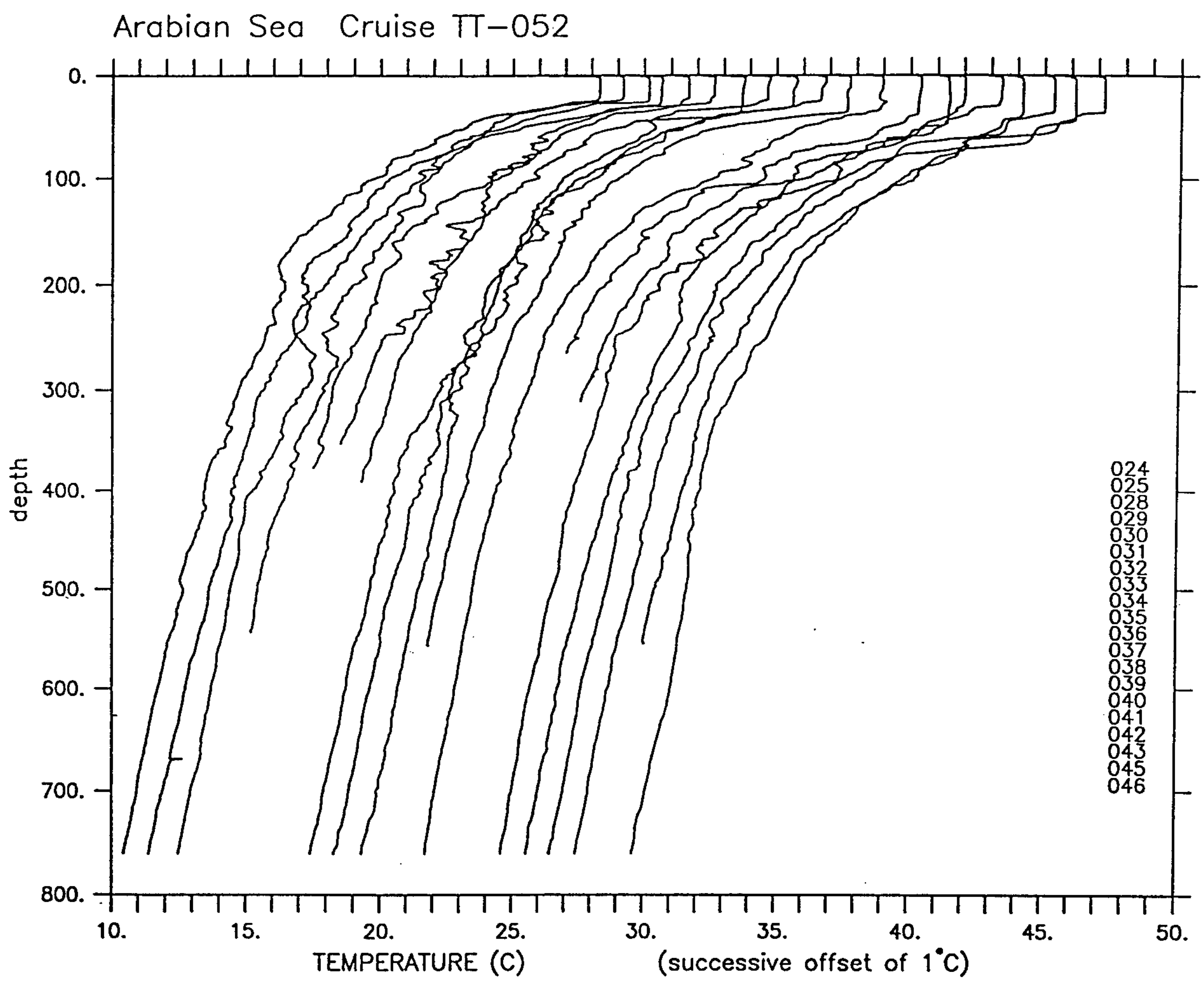


Figure A2-3: Outbound XBT overplot.

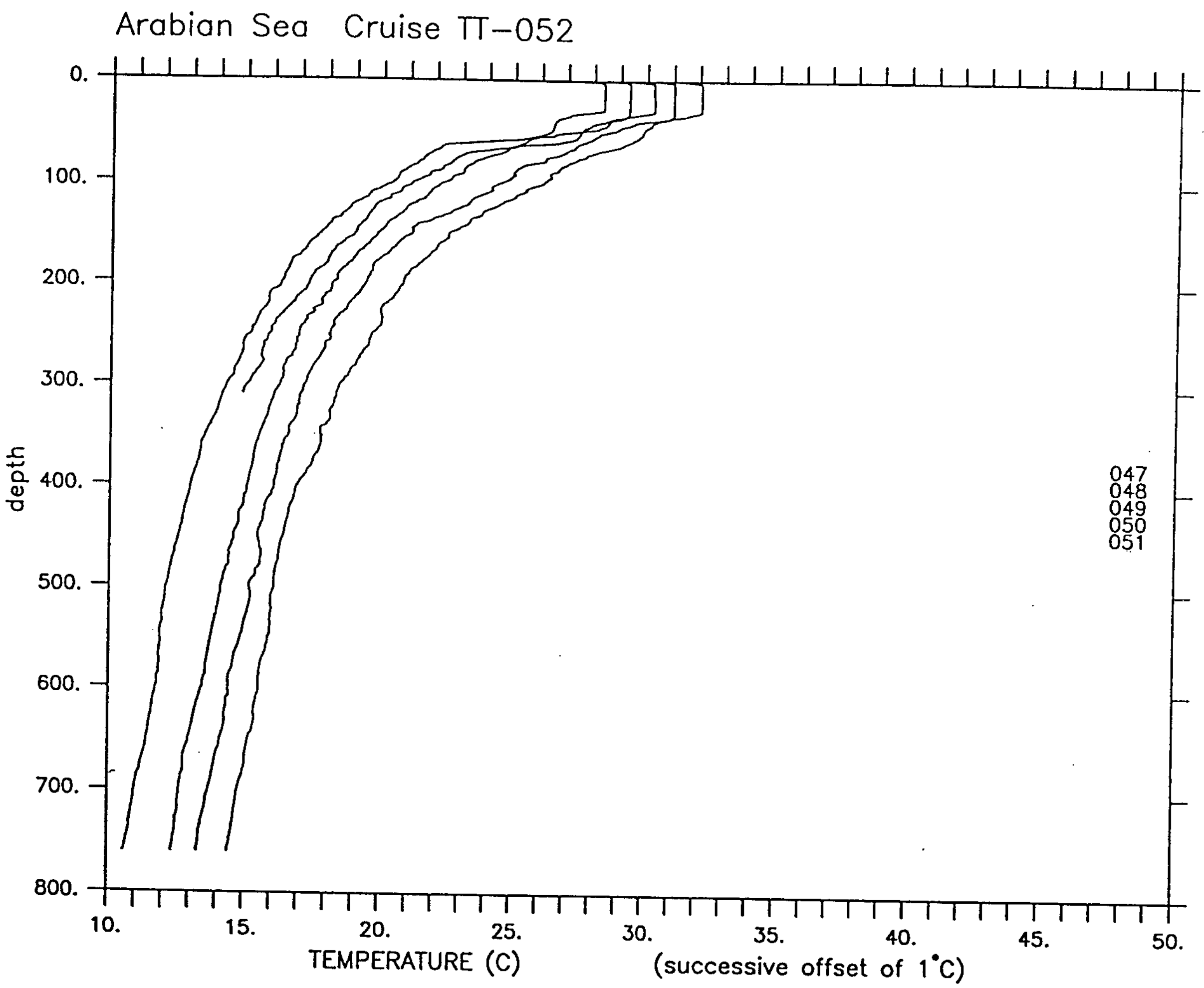


Figure A2-4: Outbound XBT overplot.

Table A2-2: TT52 Inbound XBTs

XBT#	Date	Time (UTC)	Latitude (N)	Longitude (E)	SST (°C)	Comment
52	10/21/95	00:00:00	15°56.71'	60°29.68'	28.6	(0)
53	10/21/95	00:00:00	15°59.95'	60°19.60'	28.3	(1)
55	10/21/95	02:00:00	16°00.31'	60°10.05'	28.3	(3)
56	10/21/95	03:00:00	16°01.47'	60°02.57'	28.4	(4)
59	10/21/95	04:10:00	16°03.73'	59°54.70'	28.5	(7)
60	10/21/95	04:59:00	16°06.10'	59°46.22'	28.1	(8)
61	10/21/95	05:59:00	16°08.52'	59°38.47'	28.5	(9)
62	10/21/95	06:57:00	16°10.62'	59°30.87'	28.5	(10)
63	10/21/95	08:00:00	16°12.92'	59°23.08'	28.4	(11)
65	10/21/95	08:55:00	16°15.51'	59°14.42'	28.6	(12)
66	10/21/95	09:55:00	16°18.32'	59°06.33'	29.3	(13)
67	10/21/95	10:55:00	16°21.36'	58°88.07'	29.2	(14)
68	10/21/95	11:56:00	16°25.39'	58°51.03'	28.2	(15)
69	10/21/95	12:55:00	16°27.97'	58°43.78'	28.7	(16)
70	10/21/95	13:57:00	16°30.35'	58°36.09'	29.0	(17)
71	10/21/95	14:59:00	16°32.77'	58°26.15'	28.9	(18)
73	10/21/95	16:05:00	16°35.63'	58°11.24'	28.5	(20)
75	10/21/95	17:58:00	16°41.84'	57°47.76'	28.3	(22)
76	10/21/95	18:59:00	16°45.86'	57°35.17'	28.0	(23)
77	10/21/95	19:55:00	16°48.85'	57°24.29'	28.1	(24)
78	10/21/95	20:56:00	16°52.08'	57°10.80'	26.9	(25)
79	10/21/95	21:54:00	16°55.55'	56°58.84'	28.0	(26)
80	10/21/95	22:57:00	16°56.09'	56°47.66'	27.0	(27)
81	10/21/95	23:56:00	17°00.00'	56°36.19'	27.5	(28)
82	10/22/95	00:55:00	17°03.63'	56°24.14'	27.4	(29)
83	10/22/95	01:57:00	17°03.32'	56°13.57'	27.1	(30)
84	10/22/95	02:55:00	17°06.84'	56°36.19'	27.5	(31)
86	10/22/95	04:02:00	17°12.01'	55°57.95'	27.7	(33)
87	10/22/95	04:55:00	17°15.42'	55°51.52'	28.4	(34)
88	10/22/95	05:56:00	17°19.47'	55°44.33'	29.0	(35)
89	10/22/95	06:57:00	17°24.50'	55°41.28'	28.0	(36)
90	10/22/95	07:58:00	17°25.34'	55°49.20'	28.2	(37)
91	10/22/95	08:58:00	17°25.27'	55°57.84'	28.5	(38)
92	10/22/95	09:55:00	17°26.09'	56°05.84'	28.5	(39)
93	10/22/95	10:53:00	17°25.75'	56°13.66'	28.5	(40)
94	10/22/95	11:55:00	17°25.39'	56°21.78'	28.4	(41)
95	10/22/95	12:54:00	17°25.02'	56°29.63'	28.8	(42)
96	10/22/95	13:57:00	17°28.12'	56°36.65'	28.6	(43)
97	10/22/95	14:57:00	17°29.02'	56°46.65'	28.4	(44)
98	10/22/95	16:00:00	17°29.77'	56°58.60'	28.2	(45)
99	10/22/95	16:59:00	17°30.41'	57°10.25'	28.5	(46)
100	10/22/95	17:58:00	17°31.03'	57°22.56'	28.4	(47)
101	10/22/95	18:54:00	17°31.13'	57°34.02'	28.6	(48)
102	10/22/95	19:57:00	17°39.89'	57°37.73'	27.0	(49)
103	10/22/95	20:56:00	17°48.21'	57°40.52'	28.2	(50)
104	10/22/95	21:54:00	17°56.12'	57°43.35'	28.0	(51)
105	10/22/95	22:54:07	18°04.50'	57°46.48'	28.0	(52)

XBT#	Date	Time (UTC)	Latitude (N)	Longitude (E)	SST (°C)	Comment
106	10/22/95	23:56:00	18°13.15'	57°49.71'	28.7	(53)
107	10/23/95	00:55:00	18°21.65'	57°52.86'	28.1	(54)
108	10/23/95	01:54:00	18°30.31'	57°56.17'	28.2	(55)
109	10/23/95	02:58:00	18°38.59'	57°59.50'	28.4	(56)
111	10/23/95	03:56:00	18°46.09'	58°02.62'	28.5	(57)
112	10/23/95	04:03:00	18°46.92'	58°02.93'		(58)
113	10/23/95	04:55:00	18°54.15'	58°06.19'	28.2	(59)
114	10/23/95	05:55:00	19°01.15'	58°11.54'	28.5	(60)
115	10/23/95	06:54:00	19°07.97'	58°17.27'	28.9	(61)
116	10/23/95	07:55:00	19°14.72'	58°23.26'	29.0	(62)
117	10/23/95	08:55:00	19°21.42'	58°29.23'	29.8	(63)
118	10/23/95	09:56:00	19°27.78'	58°35.09'	27.8	(64)
119	10/23/95	10:01:00	19°28.32'	58°35.56'	27.8	(65)
120	10/23/95	10:06:00	19°28.81'	58°36.00'	27.8	(66)
121	10/23/95	10:10:00	19°29.29'	58°36.39'	27.9	(67)
122	10/23/95	10:55:00	19°33.48'	58°40.08'	27.9	(68)
123	10/23/95	11:57:00	19 39.91'	58°45.03'	27.9	(69)
124	10/23/95	12:03:00	19°40.53'	58°45.49'	27.9	(70)
125	10/23/95	12:55:00	19°45.77'	58°49.15'	27.8	(71)
126	10/23/95	13:55:44	19°52.23'	58°53.80'	28.0	(72)
127	10/23/95	14:56:38	19°59.39'	58°59.15'	27.7	(73)
128	10/23/95	15:54:00	20°06.74'	59°04.80'	27.3	(74)
129	10/23/95	16:54:00	20°13.11'	59°10.73'	27.3	(75)
130	10/23/95	17:56:00	20°21.48'	59°15.26'	26.5	(76)
131	10/23/95	18:53:00	20°28.59'	59°19.49'	26.4	(77)
132	10/23/95	19:55:00	20°36.69'	59°24.73'	27.7	(78)
133	10/23/95	20:56:00	20°44.28'	59°30.09'	27.9	(79)
134	10/23/95	21:56:00	20°51.96'	59°35.31'	27.8	(80)
135	10/23/95	22:56:00	21°00.43'	59°40.10'	27.8	(81)
136	10/23/95	23:56:00	21°09.03'	59°44.64'	27.4	(82)
137	10/24/95	00:57:00	21°18.06'	59°49.48'	27.1	(83)
138	10/24/95	01:56:00	21°26.78'	59°54.15'	27.2	(84)
139	10/24/95	02:55:00	21°34.86'	59°58.80'	27.4	(85)
140	10/24/95	03:54:00	21°41.87'	60°03.17'	26.9	(86)
141	10/24/95	04:57:00	21°49.67'	60°06.89'	27.2	(87)
142	10/24/95	05:58:00	21°59.61'	60°06.61'	27.8	(881
143	10/24/95	06:55:00	22°08.56'	60°06.52'	27.9	(0)
144	10/24/95	08:55:00	22°28.73'	60°07.18'	27.9	(2)
145	10/24/95	09:56:00	22°37.81'	60°05.01 '	27.7	(3)
146	10/24/95	10:56:00	22°45.87'	60°01.66'	28.1	(4)
147	10/24/95	11:54:00	22°52.46'	59°97.75'	29.4	(5)
148	10/24/95	12:56:00	22°59.23'	59°54.12'	29.5	(6)
149	10/24/95	14:55:00	23°06.50'	59°43.43'	29.6	(8)
150	10/24/95	15:54:00	23°09.49'	59°37.86'	29.0	(9)
151	10/24/95	16:59:00	23°12.64'	59°31.84'	29.3	(10)

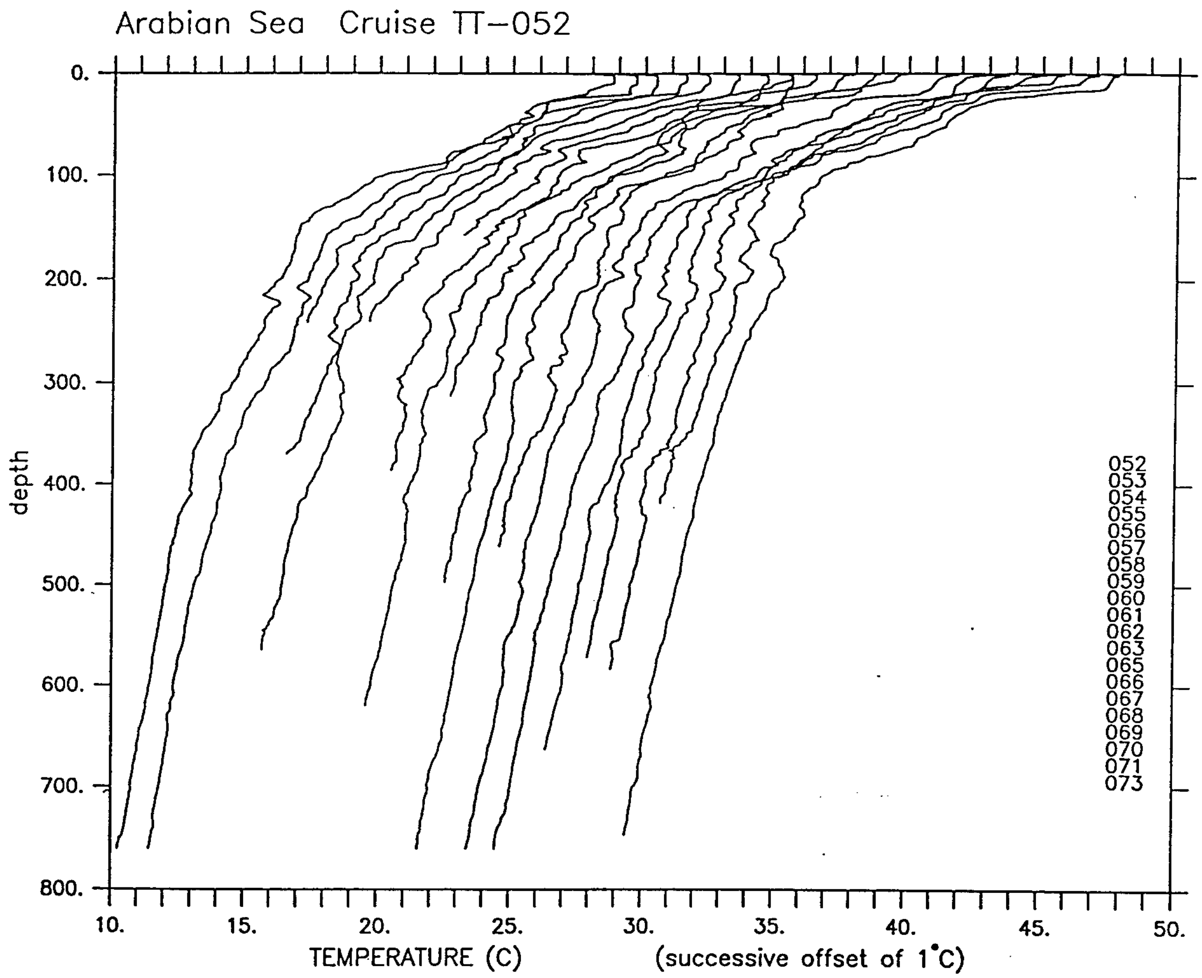


Figure A2-5: Inbound XBT overplot.

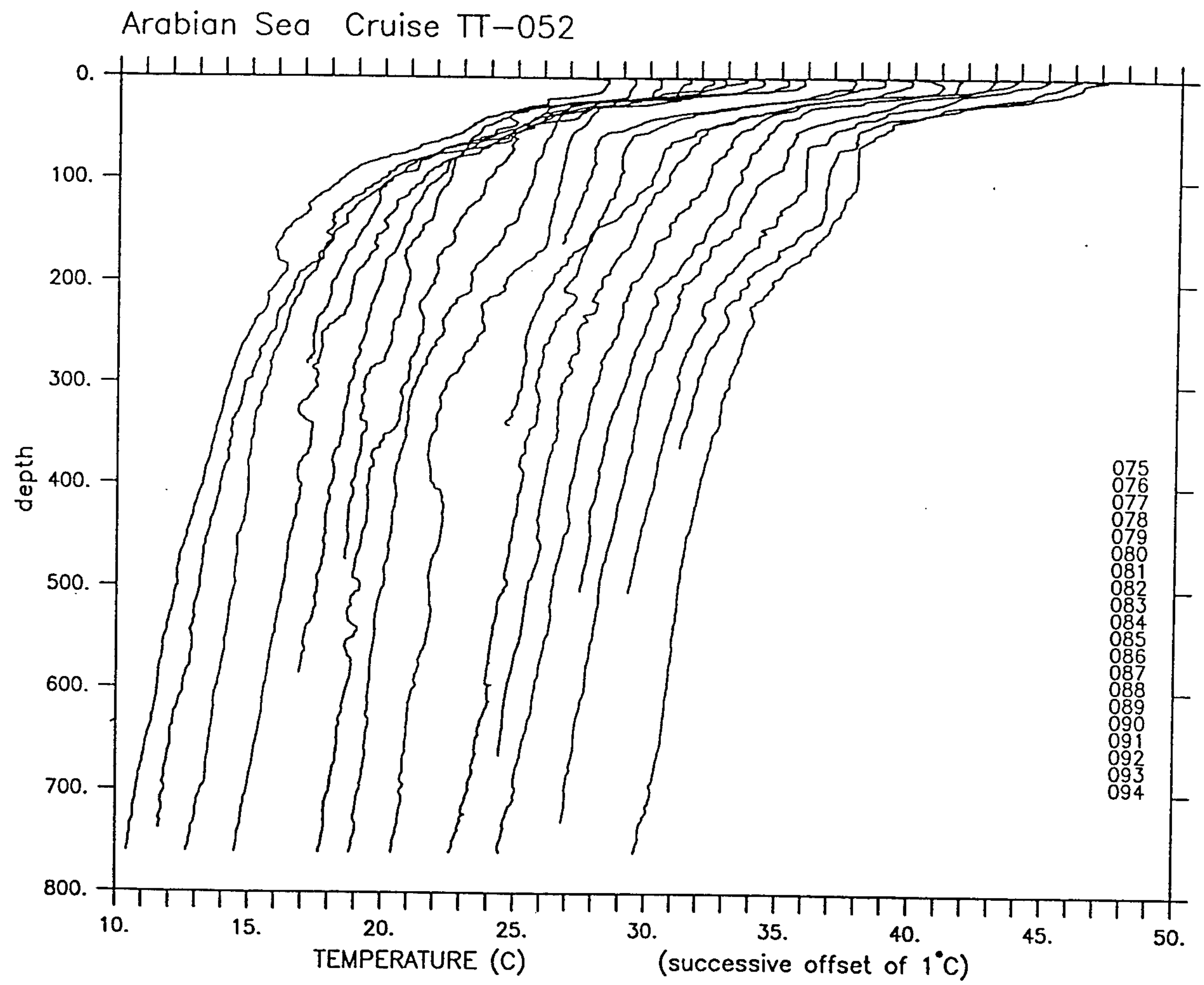


Figure A2-6: Inbound XBT overplot.

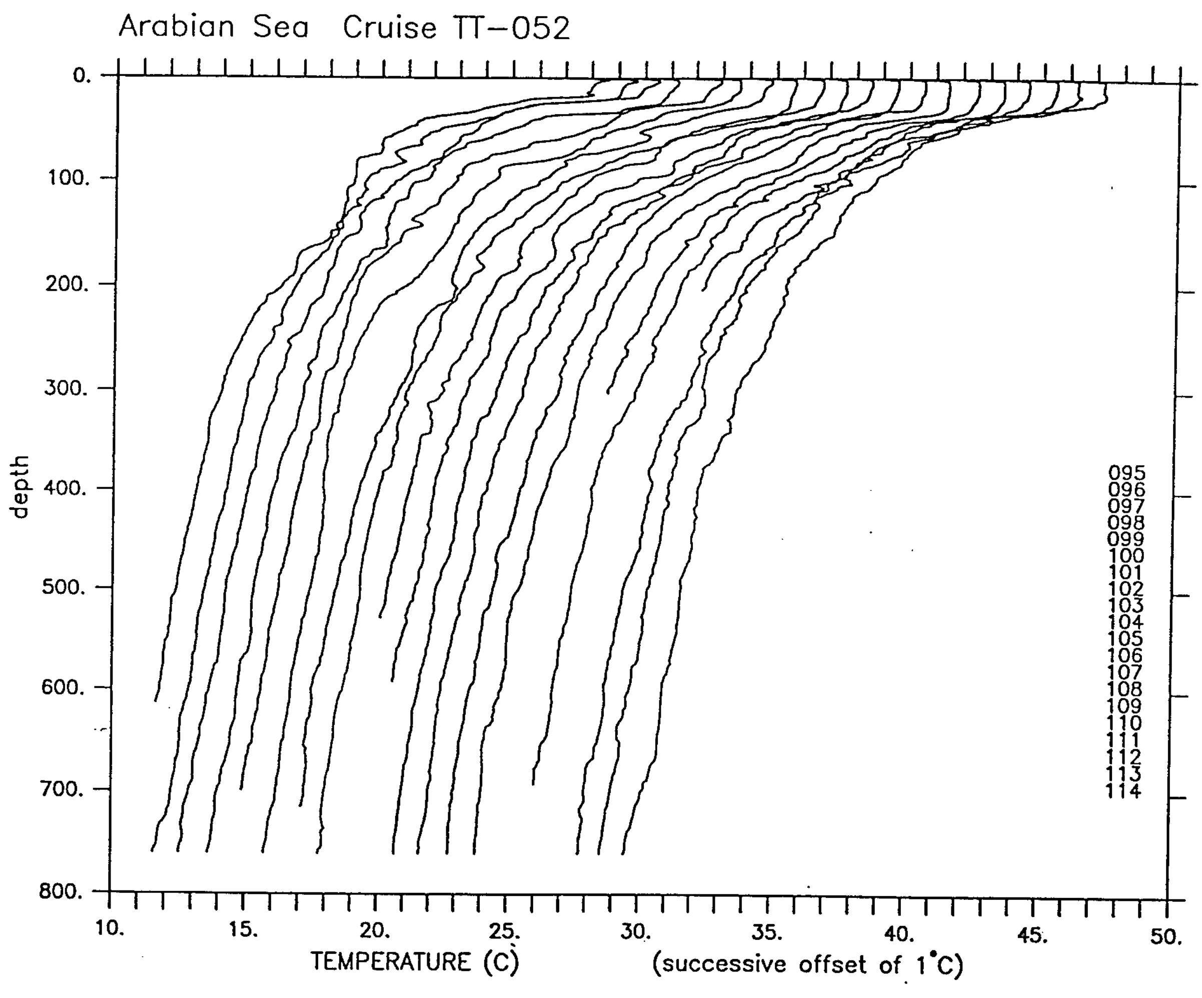


Figure A2-7: Inbound XBT overplot.

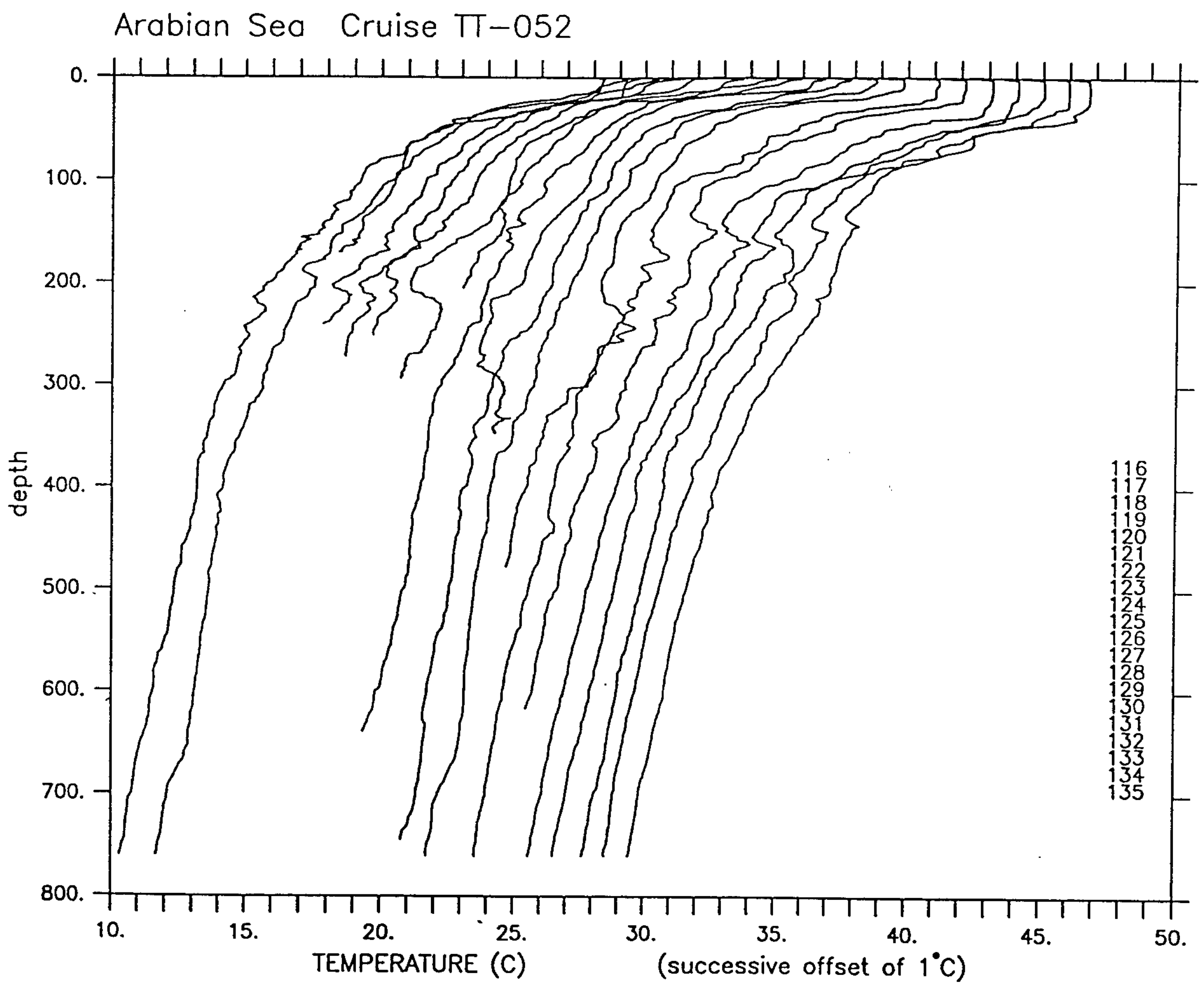


Figure A2-8: Inbound XBT overplot.

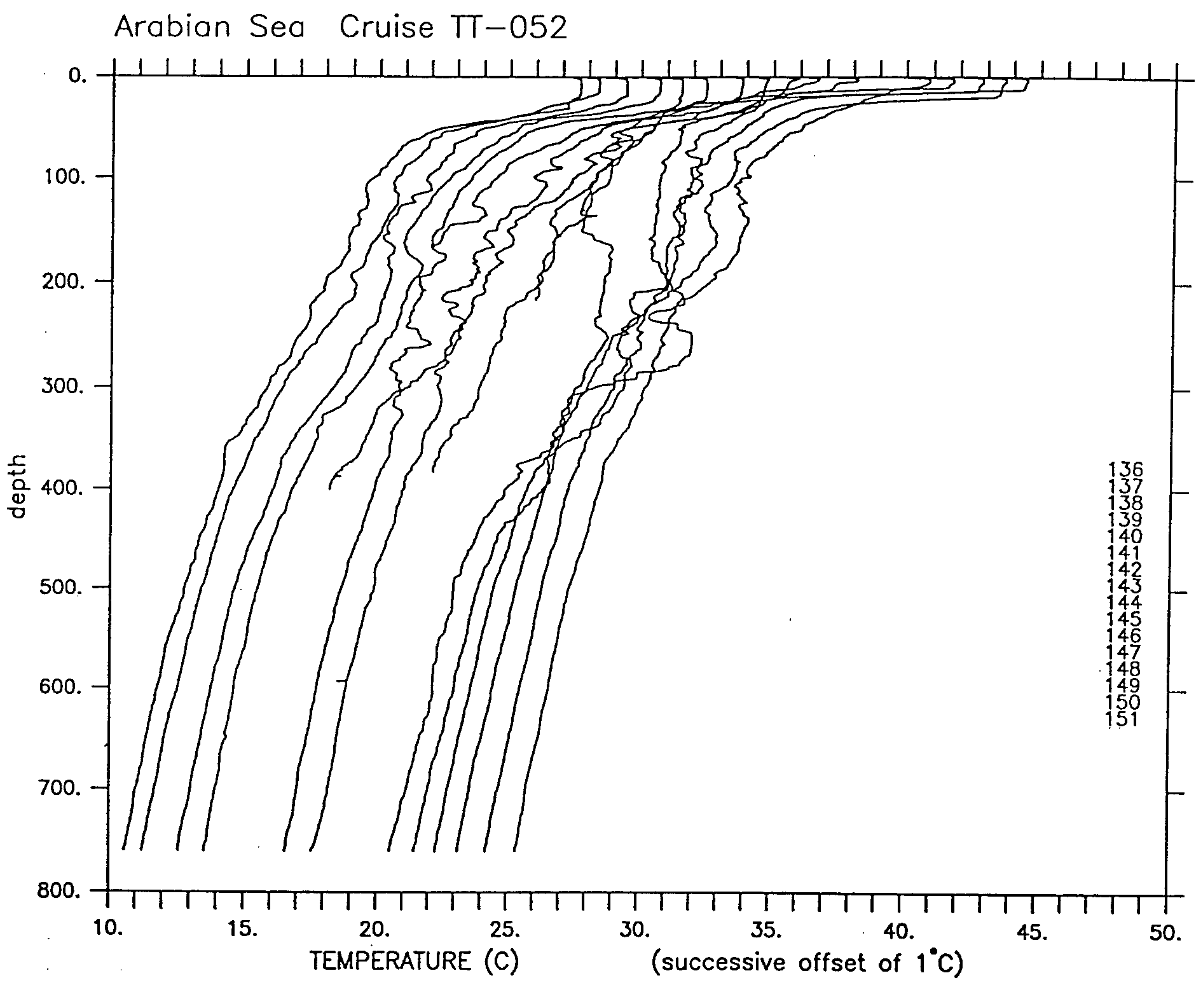


Figure A2-9: Inbound XBT overplot.

Appendix 3: CTD Positions During TN-052

During this cruise 5 CTD stations were occupied. At the locations of each of the 5 moorings, CTD profiles were made to 500 m recording depth, salinity, temperature, oxygen, transmissivity, and fluorescence. At the 5th station, near the WHOI mooring, a second profile was made to 3930 m recording depth, salinity, temperature, oxygen, and transmissivity. The 500 m stations were done to check the calibration of the salinity and temperature sensors on the moorings, to repeat similar stations done during the previous two mooring cruises, and to investigate the near-surface structure of the physical and biological properties. The deep station was done to repeat a deep station done during the previous two cruises and to obtain a full depth density profile for examining the vertical modes of the Arabian Sea.

The following table provides the positions and times of the CTD stations. The shallow and deep profiles at the WHOI mooring were labeled 5-1 and 5-2.

CTD#	Date / Time	Latitude (N)	Longitude (E)	Depth of cast
1	10/16/95 00:40:12-01:12:49	15°44.95'	61°44.81'	500 m
2	10/17/95 00:05:03-00:29:02	15°16.76'	61°44.67'	500 m
3	10/18/95 01:01:23-01:04:18	15°17.07'	61°16.54'	500 m
4	10/19/95 01:00:10-01:23:05	15°44.02'	61°16.58'	500 m
5-1	10/19/95 20:57:52-21:28:48	15°33.63'	61°35.16'	500 m
5-2	10/19/95 22:22:08- 10/20/95 00:41:59	15°33.74'	61°35.08'	3930 m

Appendix 4: Instrument Summary TN40 and TN46

Arabian Sea Instrument Summary		
Instrument No.	Mooring	Depth (meters)
Brancker Temperature Recorders		
2533	PCM South 2	250.00
2534	WHOI Central 1	300.00
2535	WHOI Central 2	90.00
2536	WHOI Central 2	125.00
2537	PCM South 1	250.00
2541	PCM North	250.00
3259	WHOI Central 1	20.00
3263	WHOI Central 2	1.49
3265	PCM South 1	20.00
3271	WHOI Central 2	2.42
3274	WHOI Central 2	1.92
3279	PCM North	20.00
3280	WHOI Central 2	0.93
3283	WHOI Central 2	30.00
3291	WHOI Central 2	0.18
3296	WHOI Central 2	60.00
3299	WHOI Central 2	0.42
3301	WHOI Central 1	90.00
3305	WHOI Central 1	30.00
3308	WHOI Central 2	175.00
3309	WHOI Central 2	40.00
3341	WHOI Central 2	4.50
3662	WHOI Central 1	0.43
3667	WHOI Central 1	1.41
3699	WHOI Central 2	72.50
3702	WHOI Central 2	225.00
3703	WHOI Central 1	40.00

Instrument No.	Mooring	Depth (meters)
Brancker Temperature Recorders Continued		
4481	WHOI Central 1	72.50
4483	WHOI Central 1	0.92
4487	WHOI Central 1	60.00
4488	WHOI Central 2	20.00
4489	WHOI Central 1	50.00
4491	WHOI Central 1	125.00
4492	WHOI Central 2	50.00
4493	WHOI Central 1	225.00
4495	WHOI Central 2	300.00
5432	WHOI Central 1	1.37
VMCM		
VM-003	WHOI Central 2	45.00
VM-011	WHOI Central 1	5.00
VM-014	WHOI Central 2	55.00
VM-015	WHOI Central 1	55.00
VM-016	PCM South 1 and 2	300.00
VM-018	PCM South 1 and 2	500.00
VM-021	PCM South 1 and 2	750.00
VM-025	PCM South 1 and 2	1500.00
VM-030	WHOI Central 2	15.00
VM-033	WHOI Central 1	45.00
VM-034	WHOI Central 2	25.00
VM-037	WHOI Central 1	15.00
VM-038	PCM South 1 and 2	3000.00
VM-039	WHOI Central 1	25.00
VM-050	WHOI Central 2	5.00

Instrument No.	Mooring	Depth (meters)
Arabian Sea Instrument Summary Continued		
MVMS		
200201-USC	WHOI Central 2	80.00
200203-USC	WHOI Central 2	35.00
203805-LD	WHOI Central 2	10.00
302703-LD	WHOI Central 1	10.00
401405-LD	WHOI Central 1	65.00
500301-LD	WHOI Central 2	65.00
500501-USC	WHOI Central 1	35.00
500601-USC	WHOI Central 1	80.00
Seacat		
142	WHOI Central 2	250.00
144	WHOI Central 2	150.00
357	WHOI Central 1	100.00
927	WHOI Central 2	100.00
928	WHOI Central 2	1.50
929	WHOI Central 2	200.00
992	WHOI Central 1	200.00
993	WHOI Central 1	250.00
994	WHOI Central 1	150.00
1179	WHOI Central 1	1.50
MTR		
3240	WHOI Central 1	3.50
3250	WHOI Central 2	3.50

Appendix 5: WHOI VMCM Record Format

1. RECORD COUNTER (TIME)

The first 16 bits (4 characters) of data comprise the record number. The counter is incremented once each data record. The first record number is one and is used to initialize the instrument. The data and length of the first record may be invalid and should be ignored. Record two contains data for the first record interval. After 65535 records, the record counter will reset to zero and begin its normal counting.

2. NORTH VECTOR

Each vector is scaled from a 24 bit accumulator and stored in a 16 bit floating-point representation. This vector is the algebraic sum of the NORTH component of current flow from each sample.

3. EAST VECTOR

Each vector is scaled from a 24 bit accumulator and stored in a 16 bit floating-point representation. This vector is the algebraic sum of the EAST component of current flow from each sample.

4. ROTOR 2 (X CURRENT FLOW) (UPPER)

The rotor counts are an algebraic sum of the counts for a record interval. Rotor counts are scaled from a 24 bit accumulator and stored as a 16 bit floating number.

5. ROTOR 1 (Y CURRENT FLOW) (LOWER)

The rotor counts are an algebraic sum of the counts for a record interval. Rotor counts are scaled from a 24 bit accumulator and stored as a 16 bit floating number.

6. COMPASS

The compass field is an 8 bit 2's complement number (-128 to+ 128 decimal). The stored value is measured at the beginning of the last sample of the record interval.

7. TEMPERATURE

One temperature sample is taken just before the end of the last record interval.

Record interval = 2 seconds to 2 hours

Sample interval = .25 seconds to 2 seconds in quarter second steps

PREAMBLE/	TIME/	NORTH/	EAST/	R2/	R1/	COMPASS/	TEMP./	PARITY
(2)	(4)	(4)	(4)	(4)	(4)	(2)	(4)	(1)

(X) = Number of characters

Appendix 6: Antifouling Coating Results

Paint testing

The Upper Ocean Processes group has over the years used Amercoat # 635 (tributyltin ablative) to anti-foul the aluminum hulls of discus buoys. Generally this coating has performed satisfactorily. It is, however, a regulated substance due to it high toxicity to non-targeted marine animals. For several years alternate coatings that are compatible with aluminum and sea water have been tested for their effectiveness as anti-foulants in current flow regimes of 0 to 4 knots for periods up to eight months.

The discus hull from the Arabian Sea 1 deployment was painted with three coats of Amercoat #635, each coat approximately 3 mils thick. Two 4 mils coats were applied 3 months prior to deployment and the third coat was applied within 14 days of immersion. There were also 6 (16" x 16") test patches positioned around the chine of the buoy as is shown in Figure A6-1. Each test patch had two sections. One half was left unpainted and was used as a control surface while the other had a nontoxic anti-corrosive underwater bridge paint called Chemotex, which was developed by CPC Corp. of Wallingford, CT. This paint is a non toxic calcium sulfinate based alkaloid that the formulators found to work well as an anti-corrosive and ablative anti-foulant over steel and aluminum substate. The Chemotex film thickness was 8 mils. and the coating was applied within 14 days of immersion.

Following the Arabian Sea 1 six month deployment, April 94–October 1995, the discus was recovered. The bio-fouling on the discus bottom was localized around the downwind area of the hull and the six solar shielded Brancker temperature loggers attached to the down current bridle leg. The six Branckers and Brancker mounting pipe were positioned on the bridle leg that was in line with the discus tower vane. The Brancker array oriented the bow of the buoy into the current. Macro algae and Gooseneck barnacles were the predominant type of bio-fouling growing in these areas. The bow or up current area of the discus hull had less fouling possibly due to greater flow against the hull's surface causing the Amercoat and Chemotex coatings to ablate away at a faster rate.

The VMCMs at 5, 10 and 15 meters depths had prolific barnacle growth attached to the instruments, stainless steel load cages and stings. A single coat of Amercoat #635 had been applied approximately 3 months prior to deployment to these VMCMs. The anti-fouling paint appeared to have oxidized causing the Amercoat #635 to not ablate at a satisfactory rate to prevent the bio-fouling. It was concluded that the coating failed due to the oxidation on the

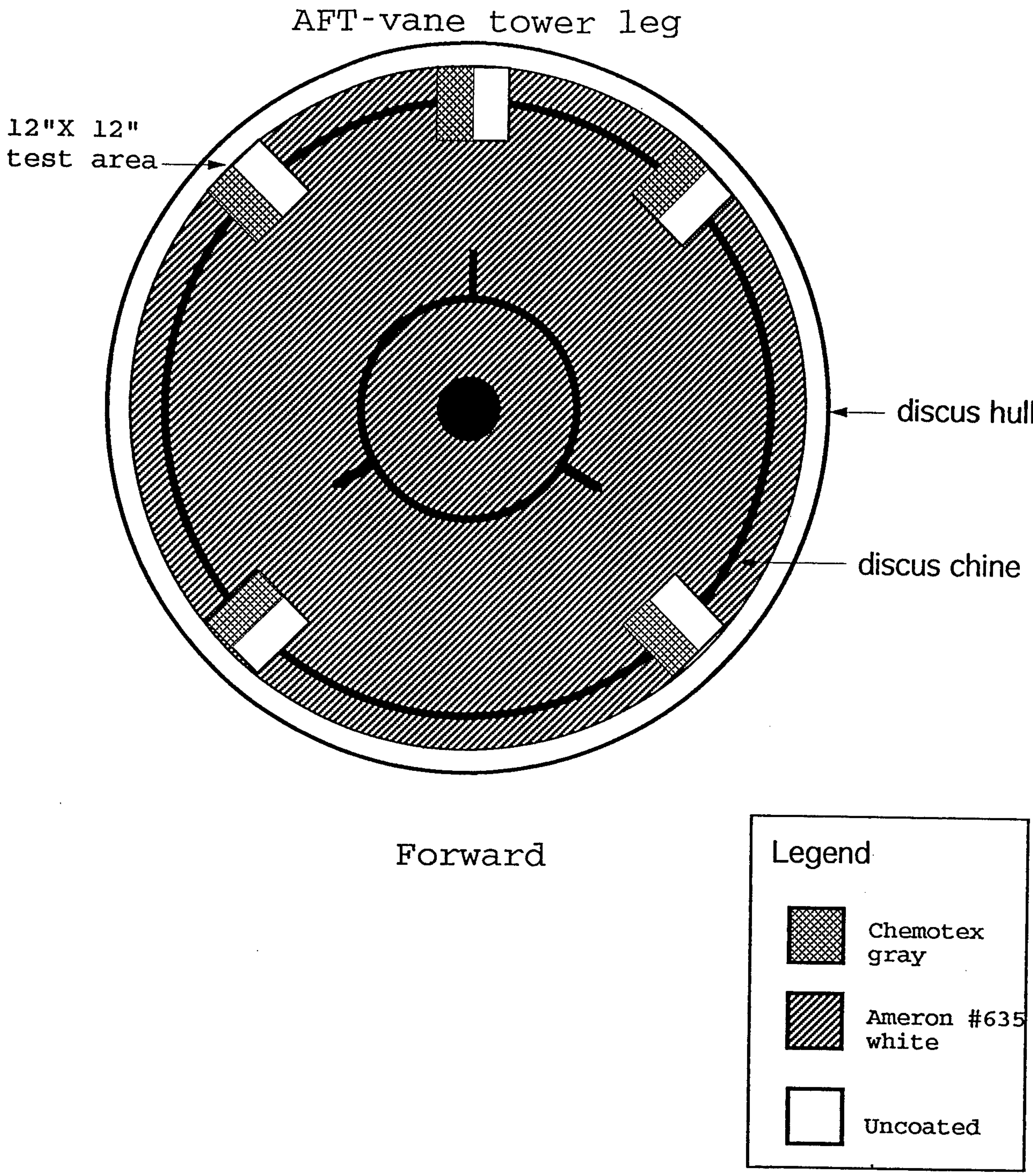


Figure A6-1: Antifouling paint test locations on the Arabian Sea 1 discus buoy hull.

coating which resulted from the extended period of time between painting the cages and the time of immersion.

The discus hull for the Arabian Sea 2 deployment and three VMCM cages at 5 ,10 and 15 meters depth were coated with three varieties of anti-fouling paint. The coatings used were Amercoat #635 (white), Chemotex (gray), and No Foul (black). No Foul is a non-toxic hydrogen peroxide release ablative developed by E Paint Company Inc., Bourne, Mass. The discus buoy had five test areas located around the chine. Figure A6-2 illustrates the position of these test areas. Each test area was divided into three 4" x 16 sections. One section was left uncoated and acted as the control for the test. The two sections remaining had three .004 thick coats of No Foul and Chemotex applied to the test sections. Amercoat #635 was used to coat the remainder of the hull and six Branckers attached to the discus bride leg. The Amercoat #635 had three coats applied totaling 12 mils in thickness. The VMCM instrument case, sting and three of the 3/4" load cage rods were painted with Amercoat #635. The fourth cage rod was used as a test surface for the No Foul and Chemotex paints. Two coats with approximately .008 film thickness were applied to this cage rod. The instruments were painted 36 hours prior to deployment.

When the discus surface mooring was recovered there was a significant lack of fouling to the discus hull and subsurface instrumentation down to 150 meters in comparison to the prolific fouling that occurred during the first discus deployment. The Amercoat #635, No Foul and the Chemotex paints performed equally well during this deployment. These coatings had approximately .006 greater mil thickness than what was applied to the Arabian Sea 1 discus and VMCM cages. The untreated areas had greater fouling than the coated areas. From the results of this test three conclusions can be drawn. There is a correlation between the thickness of the paint and its effectiveness in preventing bio-fouling. These coatings performed better if the period of time from coating to immersion is minimized. The time of the year pays a very important role in the potential for fouling.

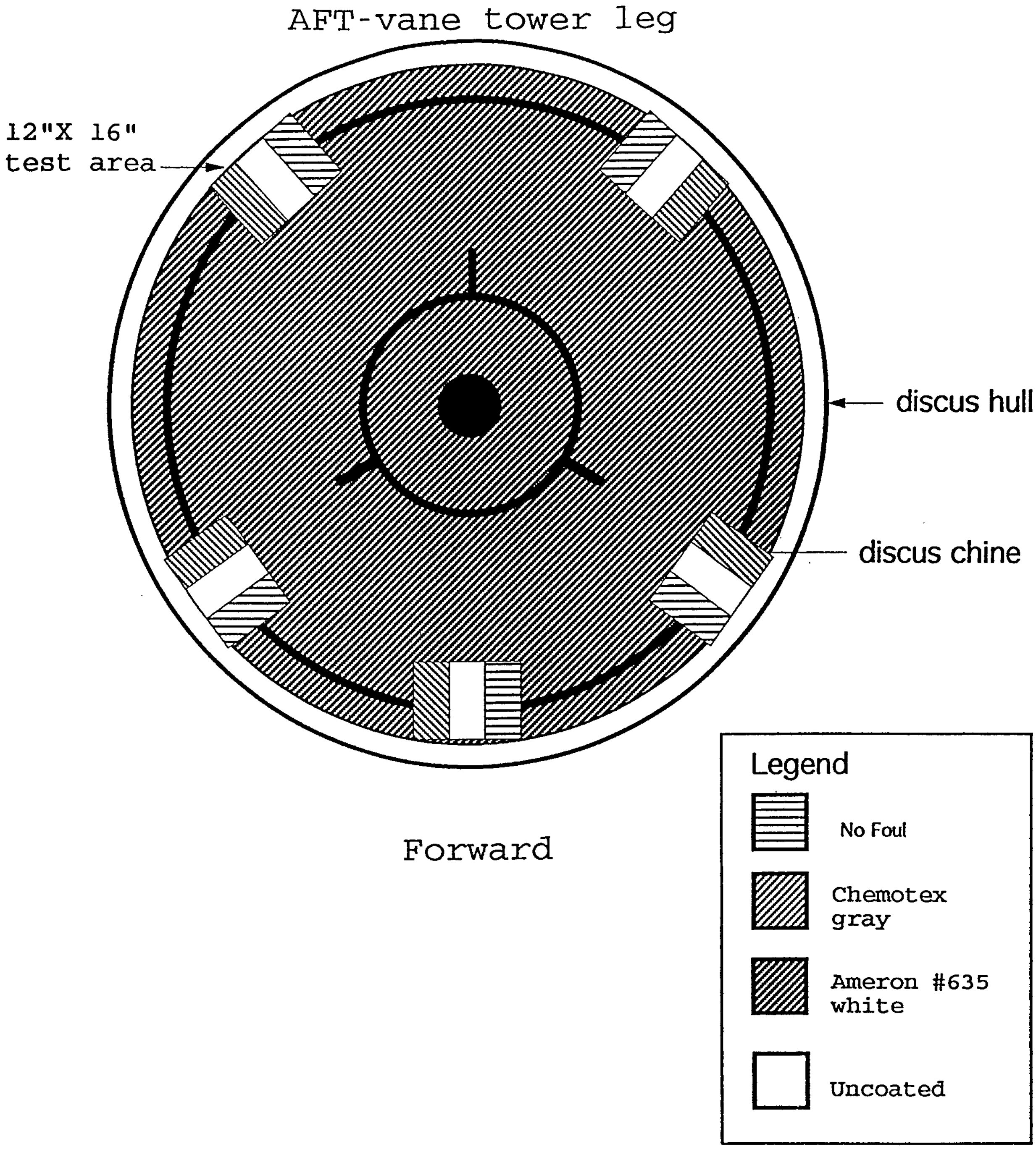
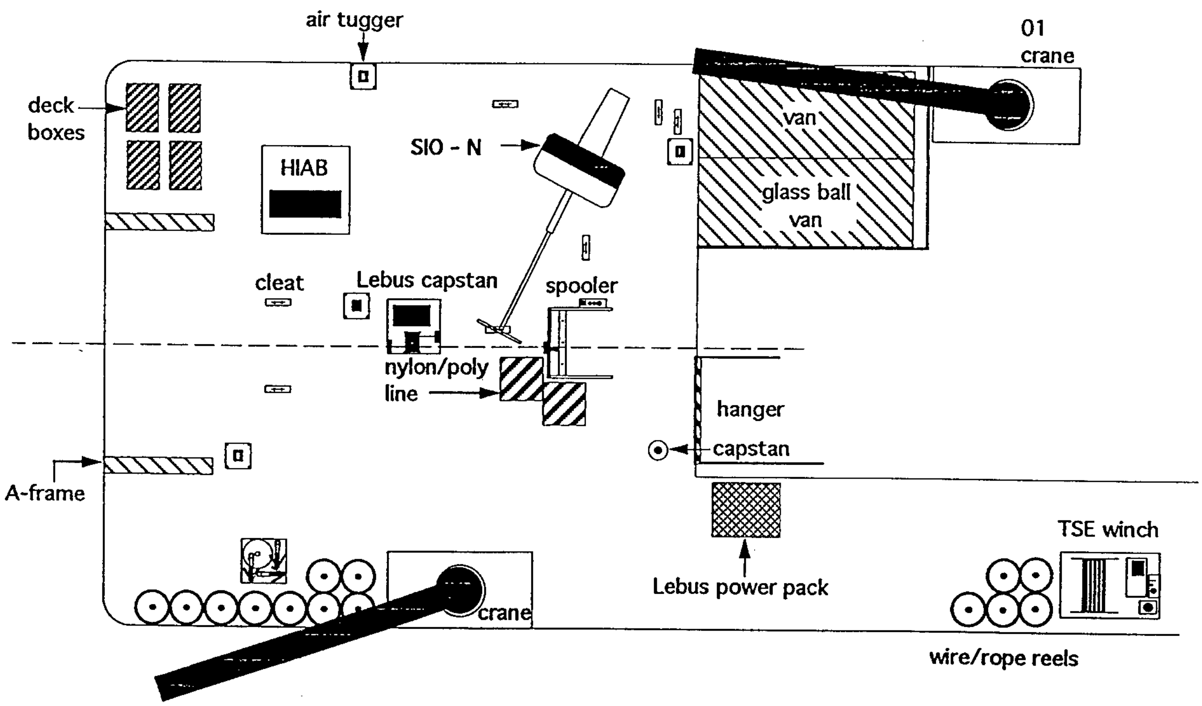
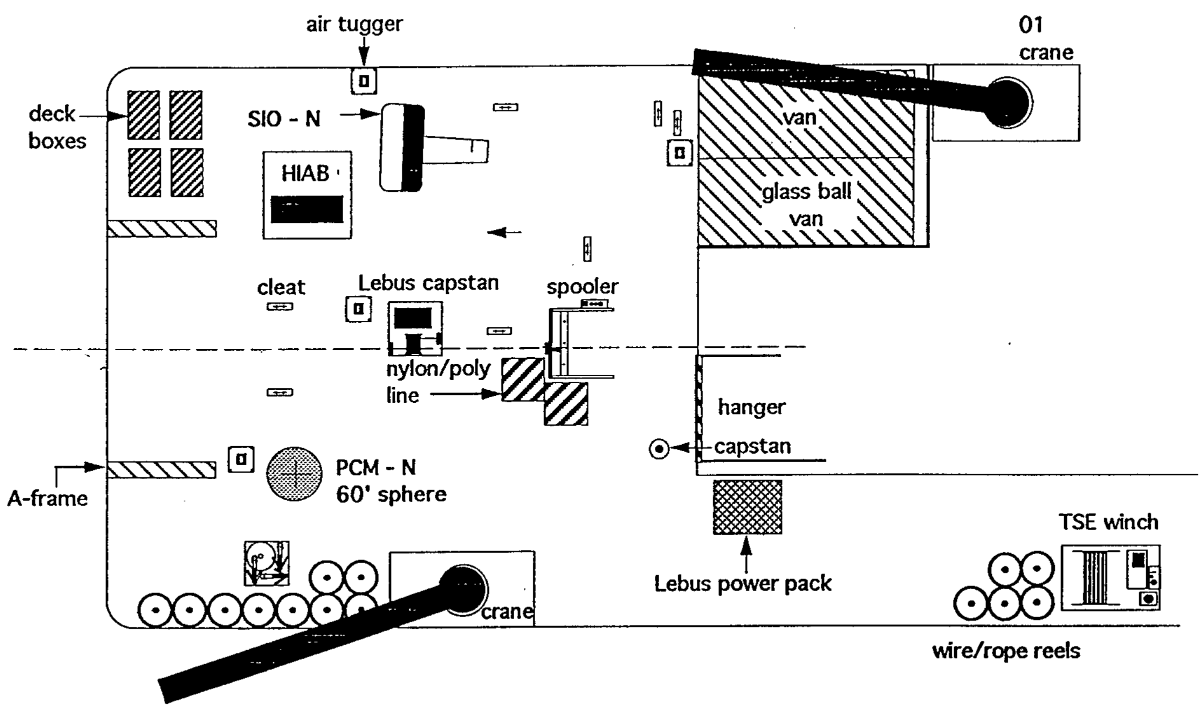


Figure A6-2: Antifouling paint test locations on the Arabian Sea 2 discus buoy hull.

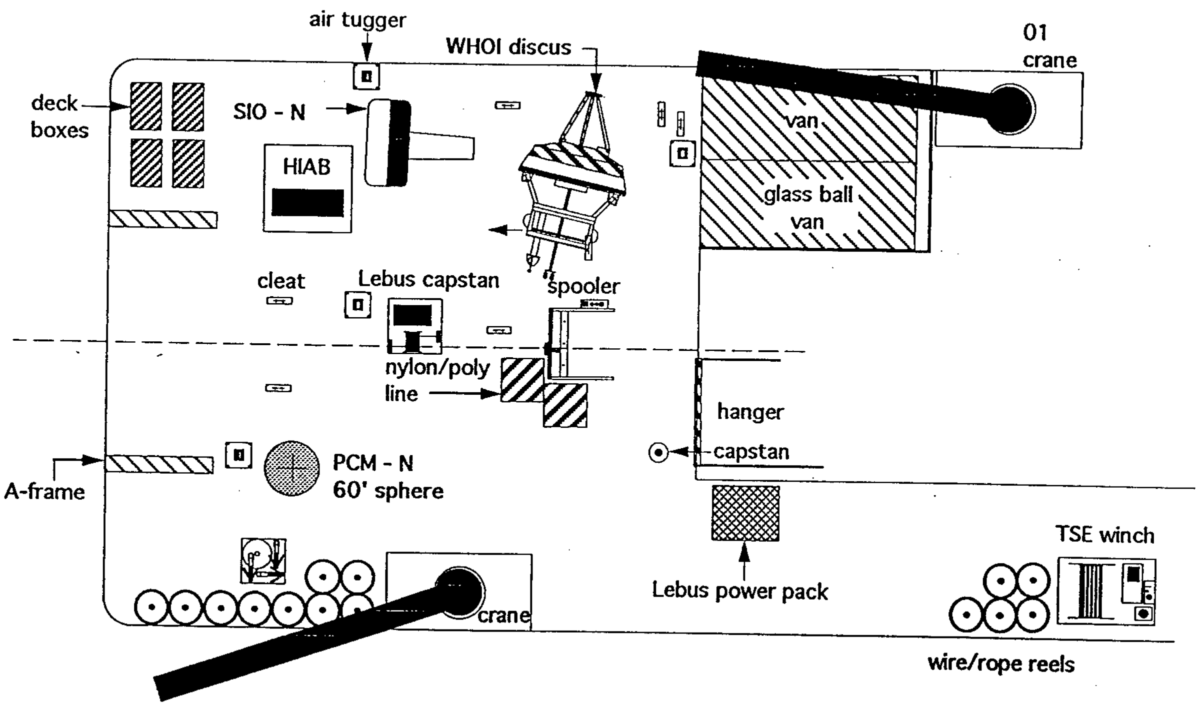
Appendix 7: Deck Layout Drawings



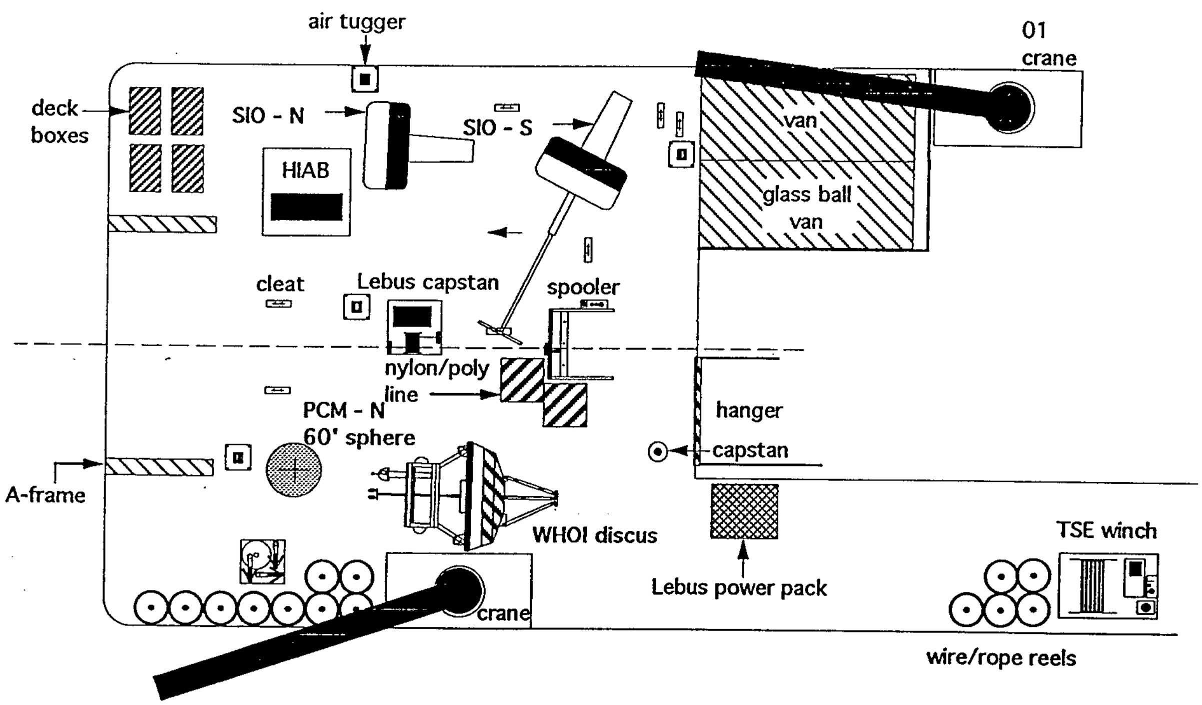
Arabian Sea
R/V Thompson
10/2/95
W.Ostrom
phase #1
SIO North recovery
scale 1"= 15'
appendix 7a



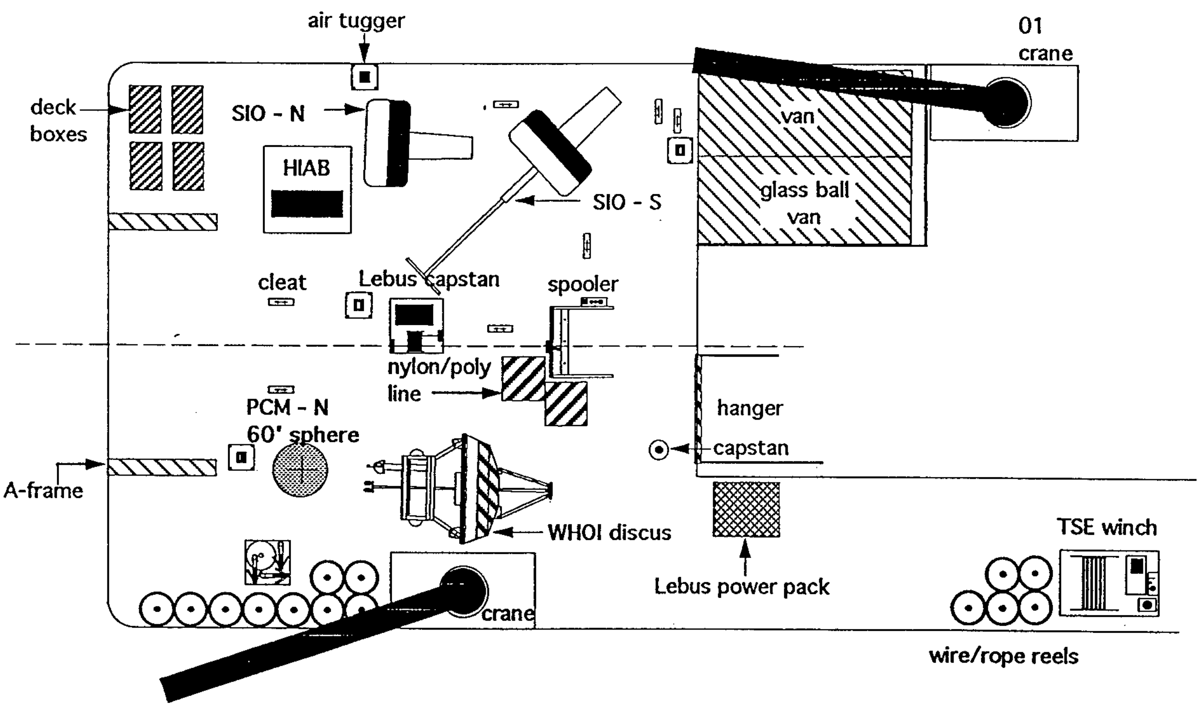
Arabian Sea
R/V Thompson
10/2/95
W.Ostrom
phase #2
PCM North recovery
scale 1"= 15'
appendix 7b



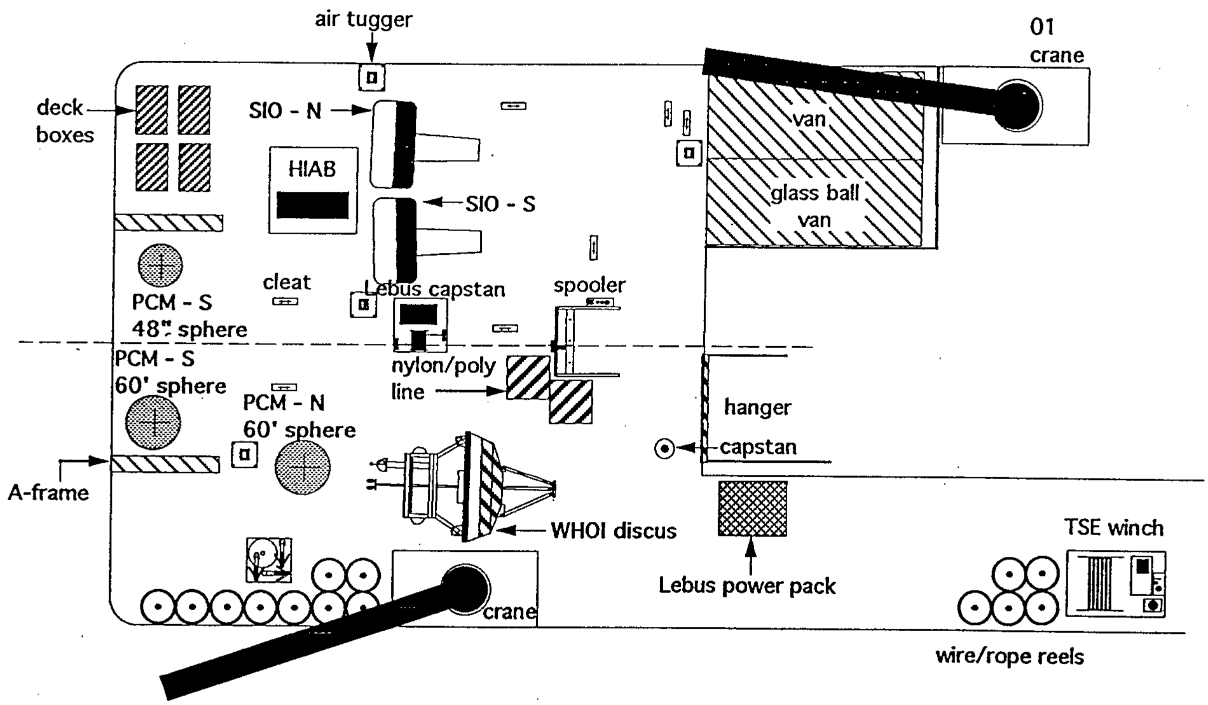
Arabian Sea
R/V Thompson
10/2/95
W.Ostrom
phase #3
WHOI discus recovery
scale 1"= 15'
appendix 7c



Arabian Sea
R/V Thompson
10/2/95
W.Ostrom
phase #4
SIO South recovery
scale 1"= 15'
appendix 7d



Arabian Sea
R/V Thompson
10/2/95
W.Ostrom
phase #5
SIO - S recovery
scale 1"= 15'
appendix 7e



Arabian Sea
R/V Thompson
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W.Ostrom
phase #6
PCM - S recovery
scale 1"= 15'
appendix 7f

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16. Abstract (Limit: 200 words)

An array of surface and subsurface moorings was deployed in the Arabian Sea to provide high quality time series of local forcing and upper ocean currents, temperature, and conductivity in order to investigate the dynamics of the ocean's response to the monsoonal forcing characteristic of the area. The moored array was first deployed during R/V *Thomas Thompson* cruise number 40; recovered and redeployed during R/V *Thomas Thompson* cruise number 46 and recovered to conclude the deployment during R/V *Thomas Thompson* cruise number 52. The array was part of the Office of Naval Research (ONR) funded Arabian Sea experiment.

This report describes, in a general manner, the work that took place during the R/V *Thomas Thompson* cruise number 52. A detailed description of the Woods Hole Oceanographic Institution (WHOI) surface mooring and its instrumentation is provided. Information about the XBT and CTD data and near surface temperature data collected during the cruise is also included.

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Arabian Sea

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